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**Sthoeger et al.**

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(54) **SYSTEM AND METHOD OF SENDING DATA VIA ADDITIONAL SECONDARY DATA LINES ON A BUS**

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**G06F 1/12** (2006.01)

(52) **U.S. Cl.**  
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(Continued)

(58) **Field of Classification Search**  
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See application file for complete search history.

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*Primary Examiner* — Eric Oberly

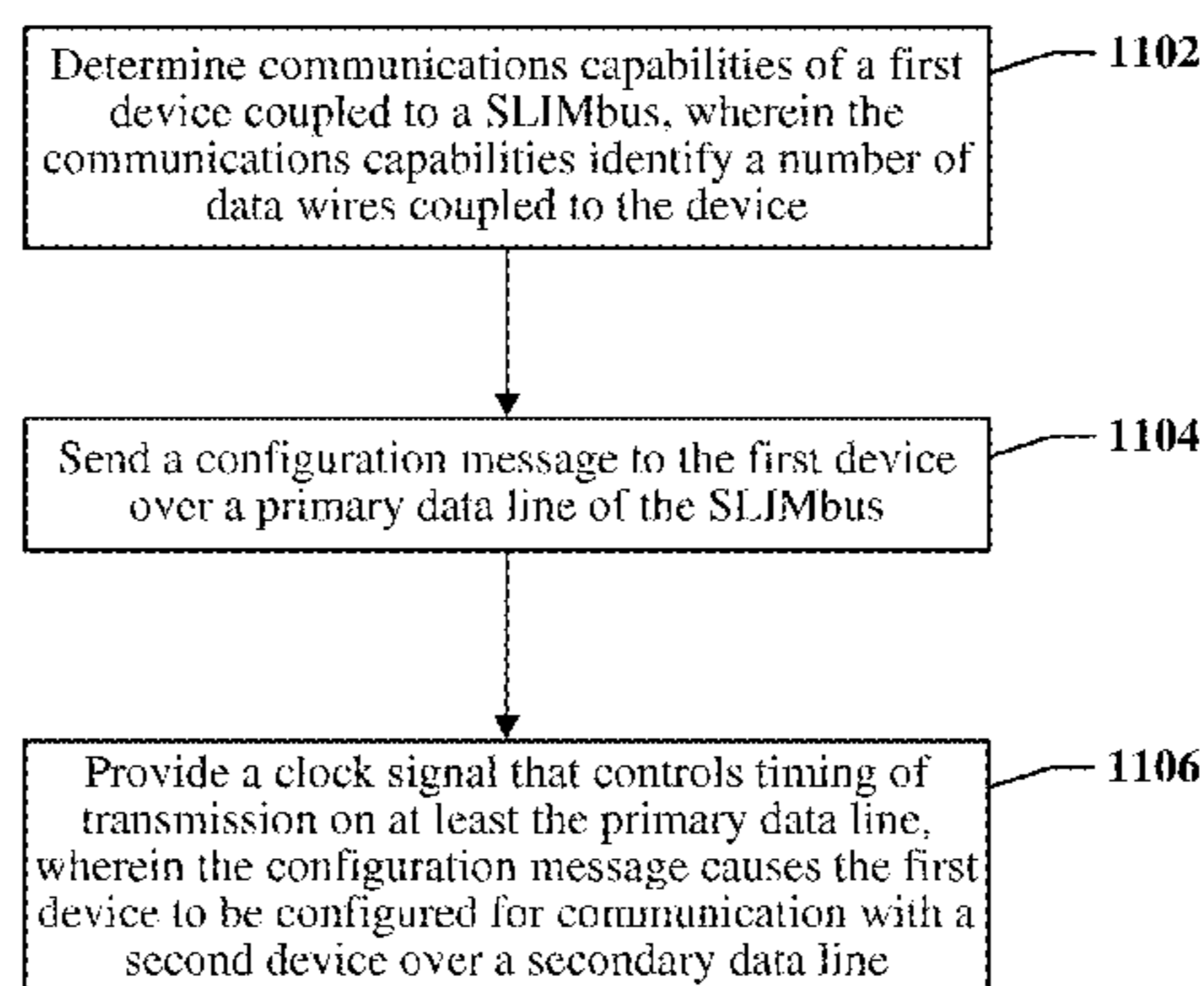
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(57) **ABSTRACT**

A serial low-power inter-chip media bus communications link is deployed in apparatus having multiple Integrated Circuit devices. Communications capabilities of a device coupled to the communications link may be determined and configuration or framing message may be sent to the first device based on the capabilities. The messages may be transmitted on a primary data line of the communications link with a clock used to control timing of transmission on at least the primary data line. The communications capabilities can include information identifying a number of data wires supported by or coupled to the device. A first device may be configured to communicate with a second device over a secondary data line, which may be reserved for such direct communication. Communications on the secondary data line may be synchronized using the clock signal and may be controlled by a different protocol than the protocol used for the primary data line.

**30 Claims, 14 Drawing Sheets**

1100 ↗



(52) **U.S. Cl.**  
CPC ..... **G06F 13/4291** (2013.01); **Y02B 60/1228**  
(2013.01); **Y02B 60/1235** (2013.01)

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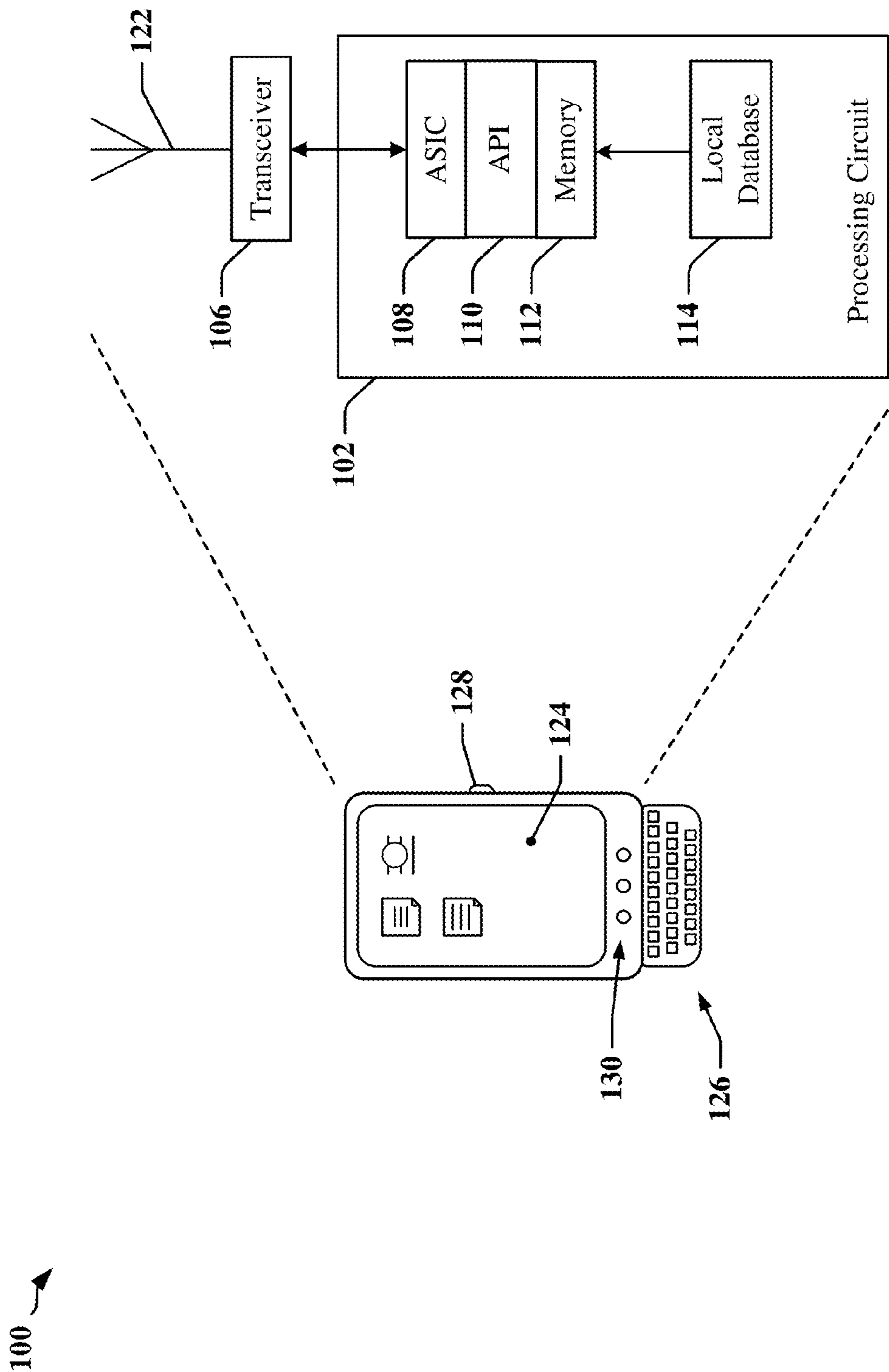
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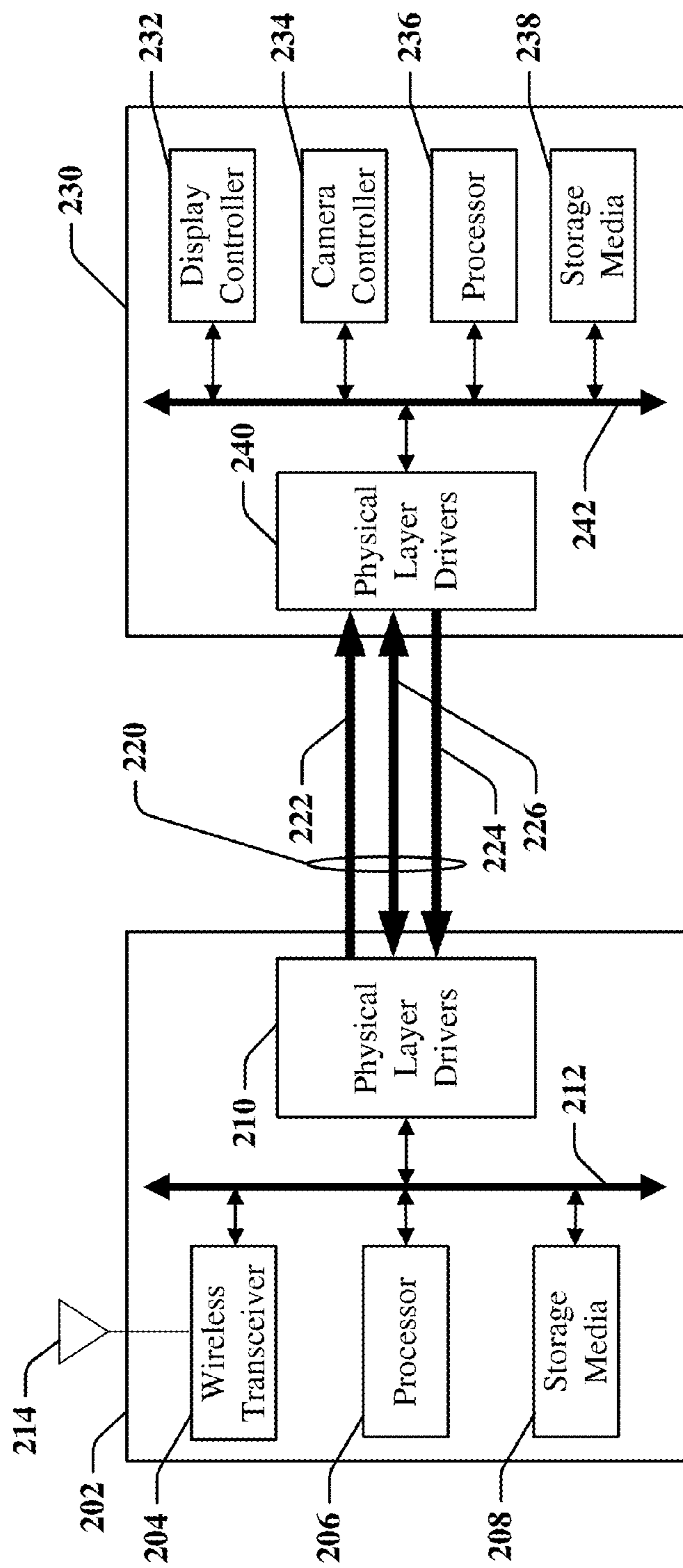
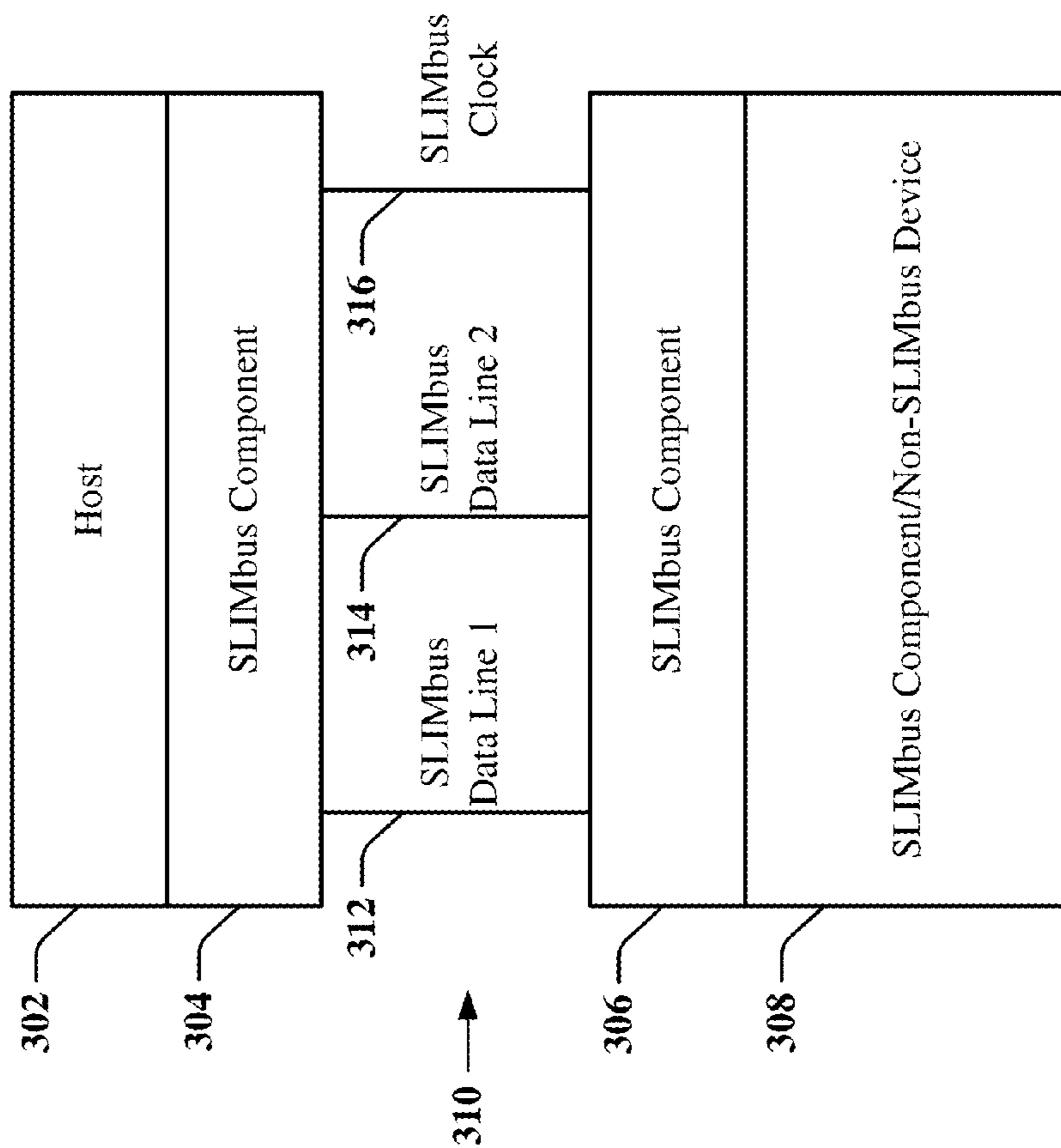


FIG. 2

300 ↗



**FIG. 3**



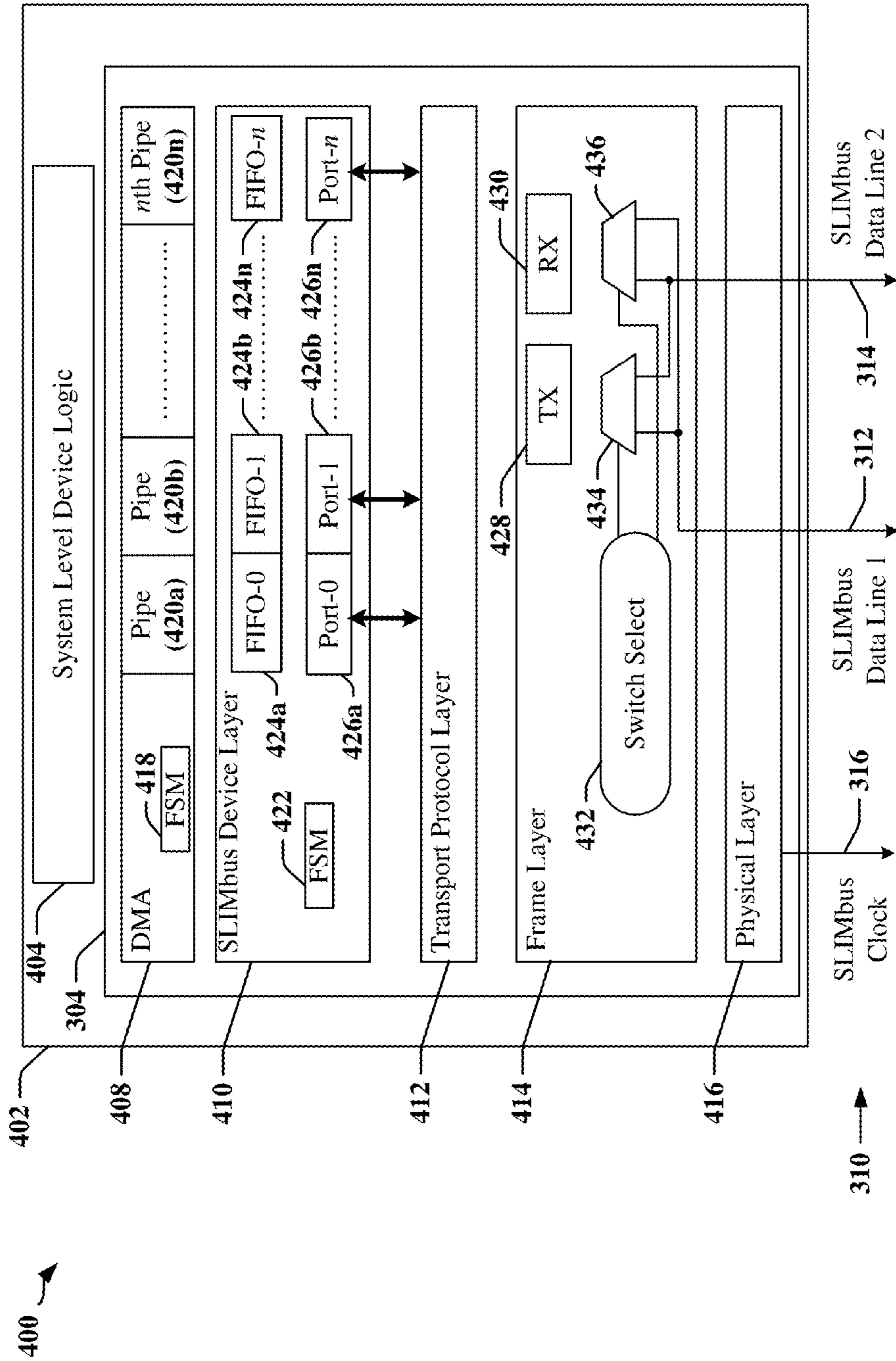


FIG. 4

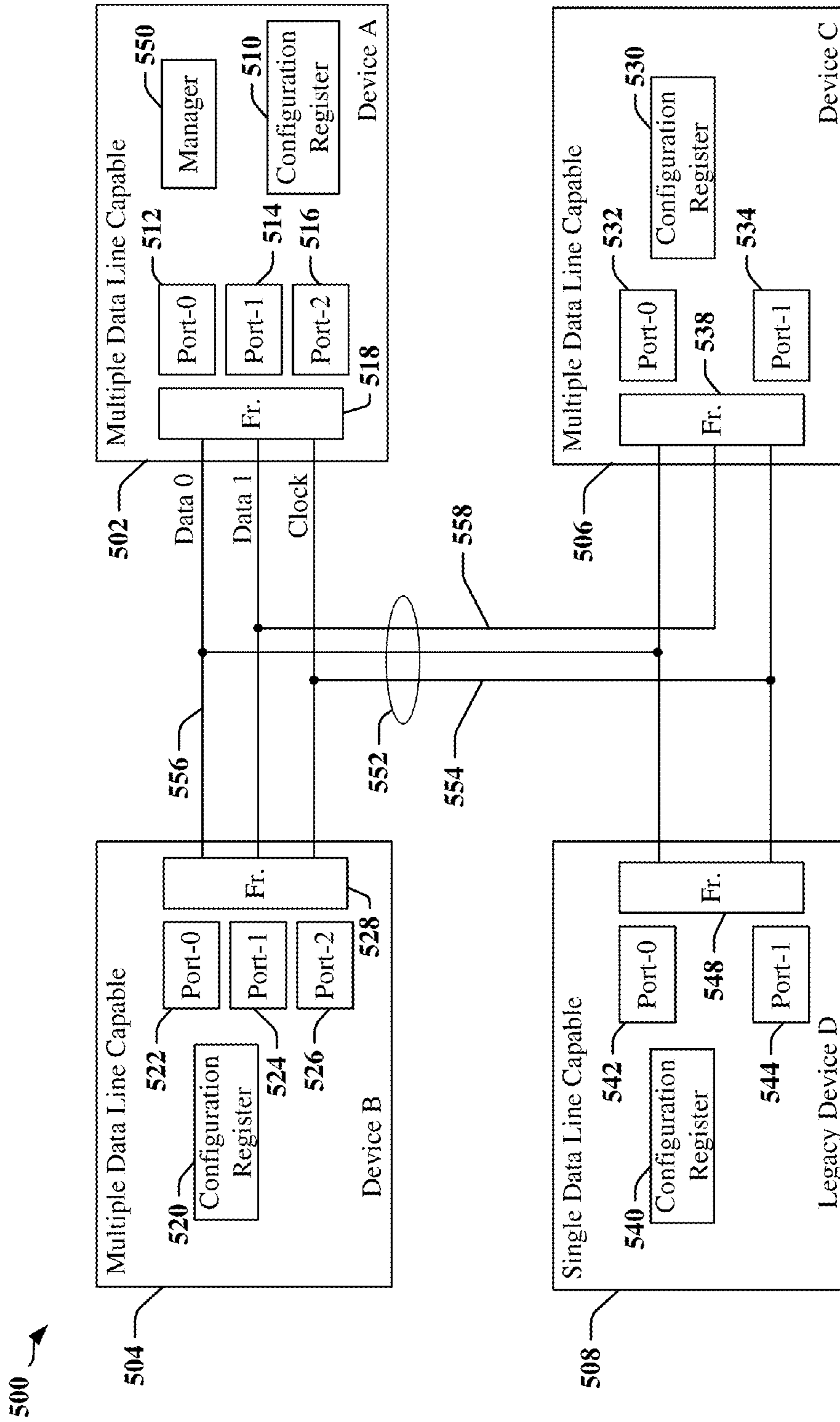


FIG. 5

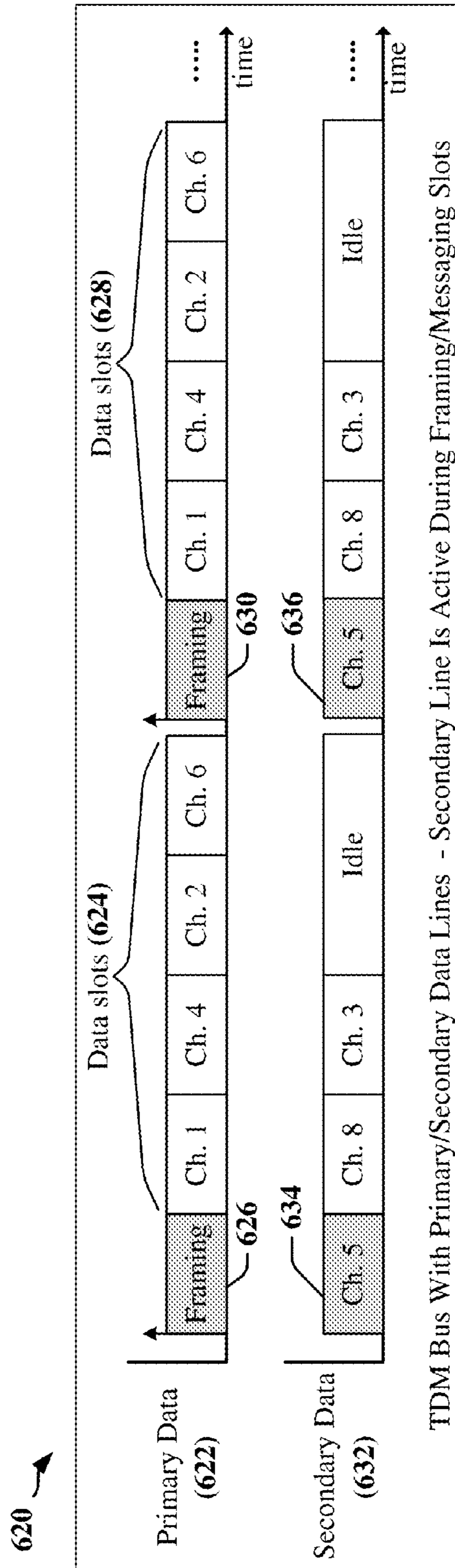
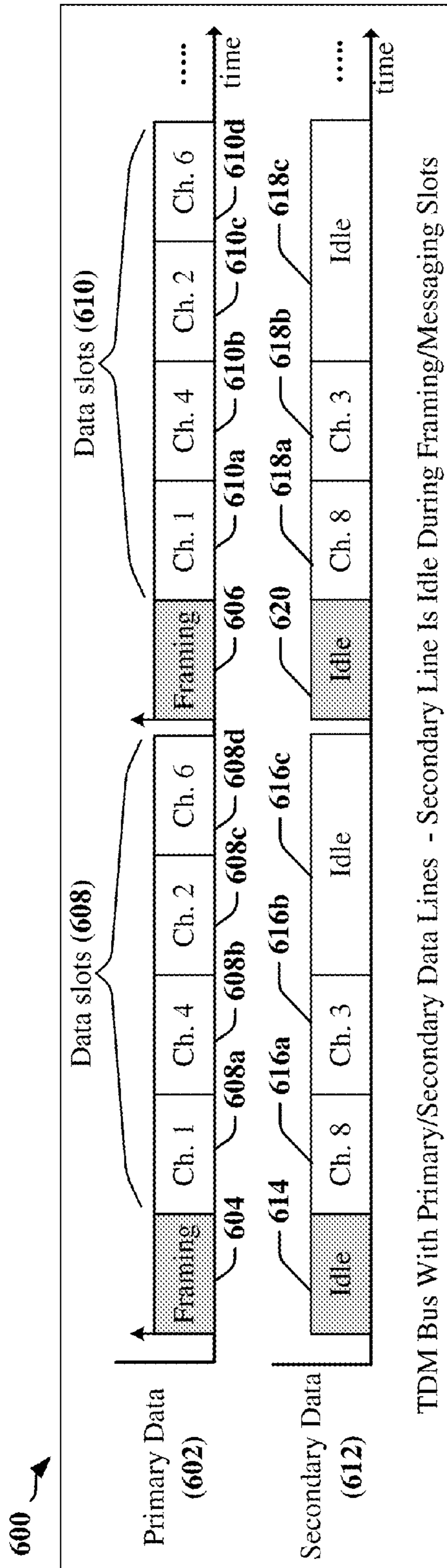


FIG. 6



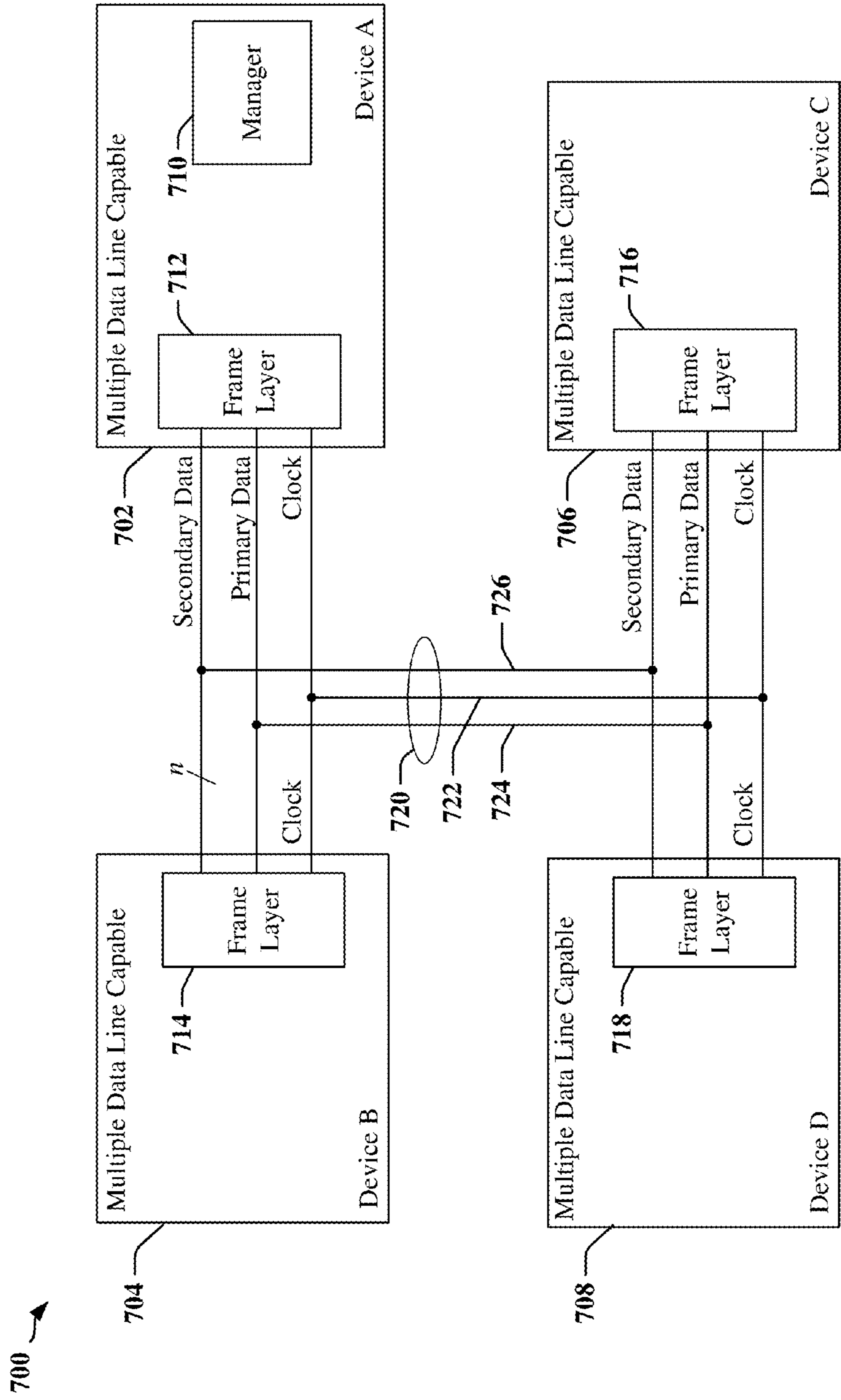


FIG. 7

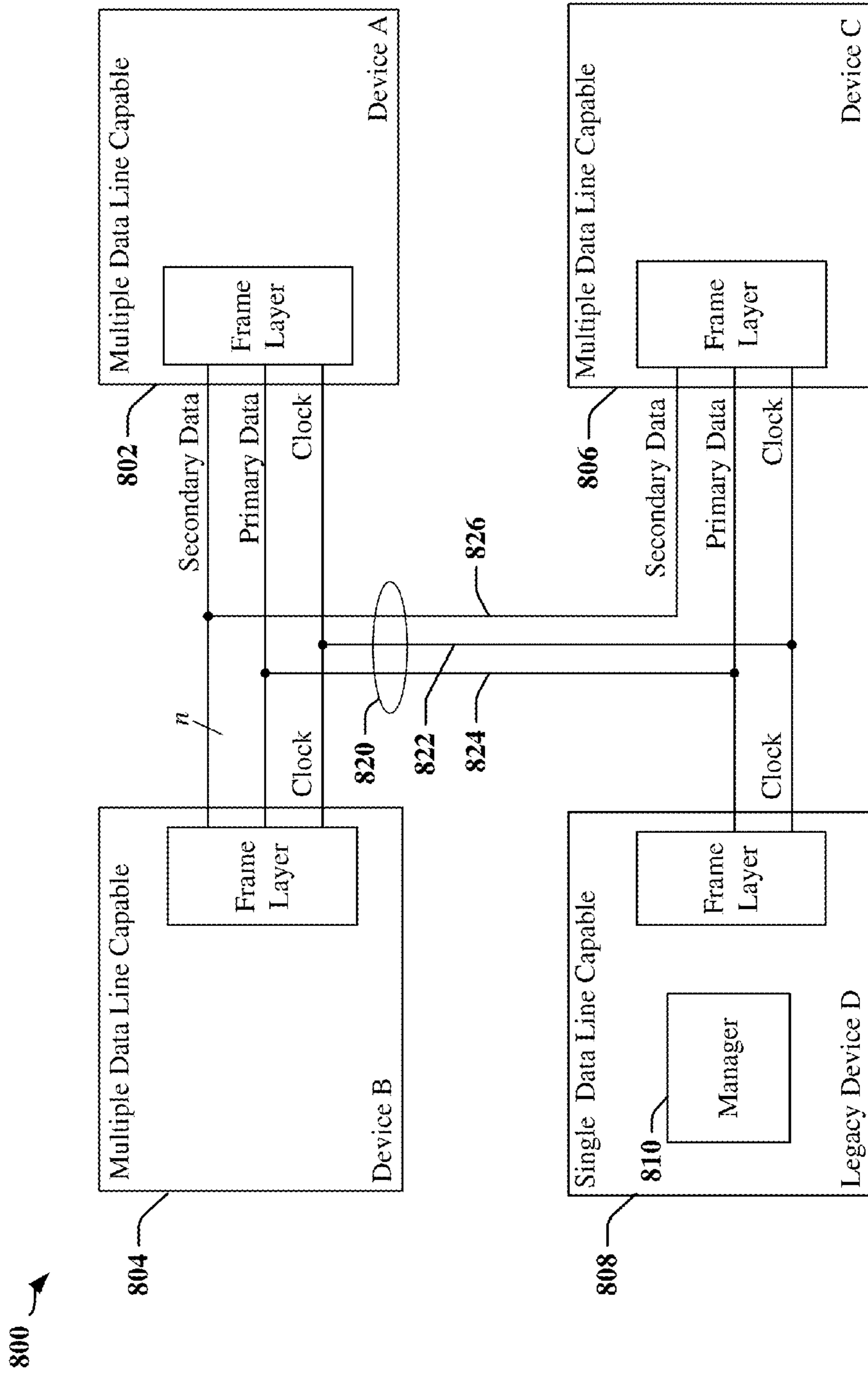


FIG. 8

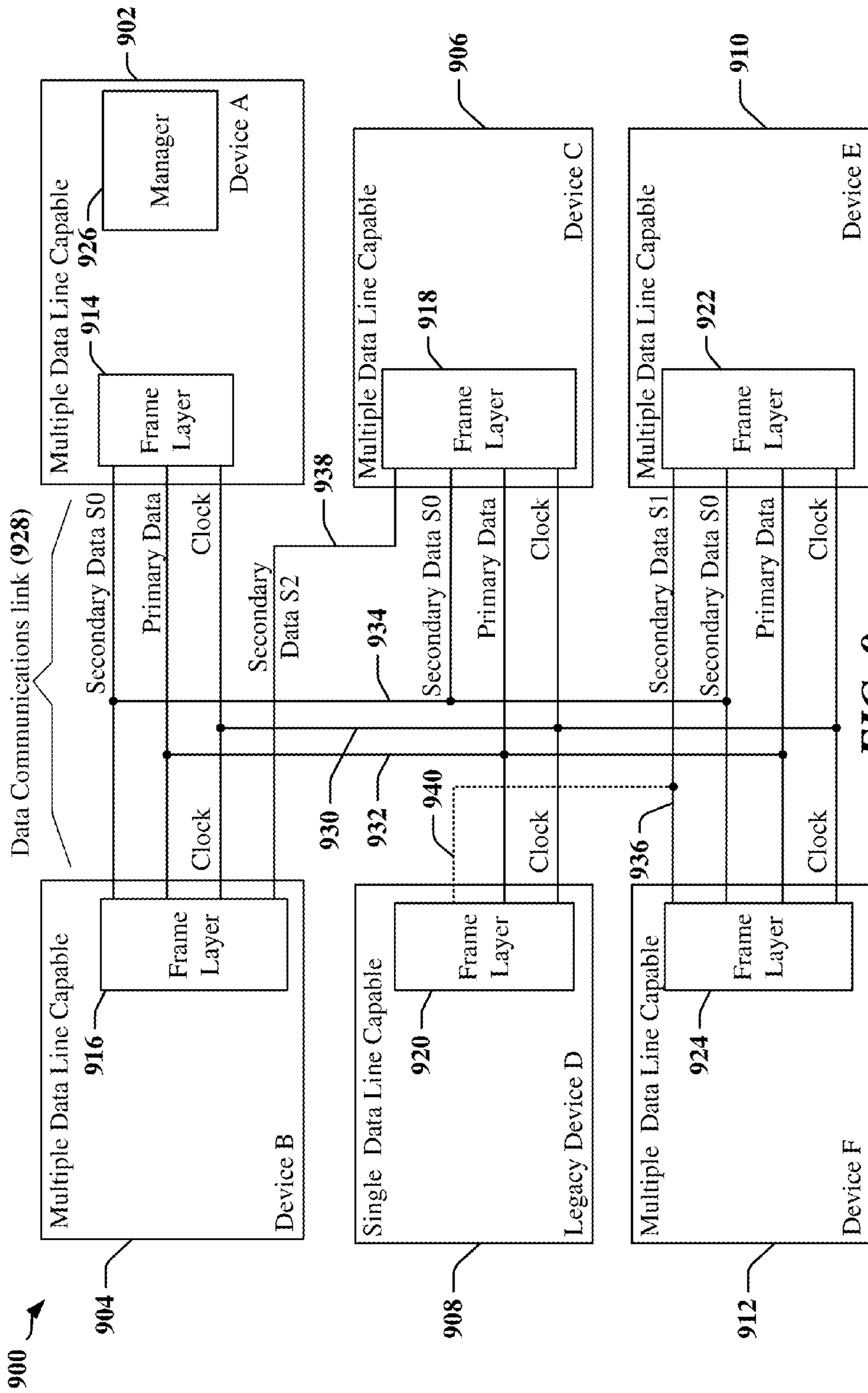


FIG. 9

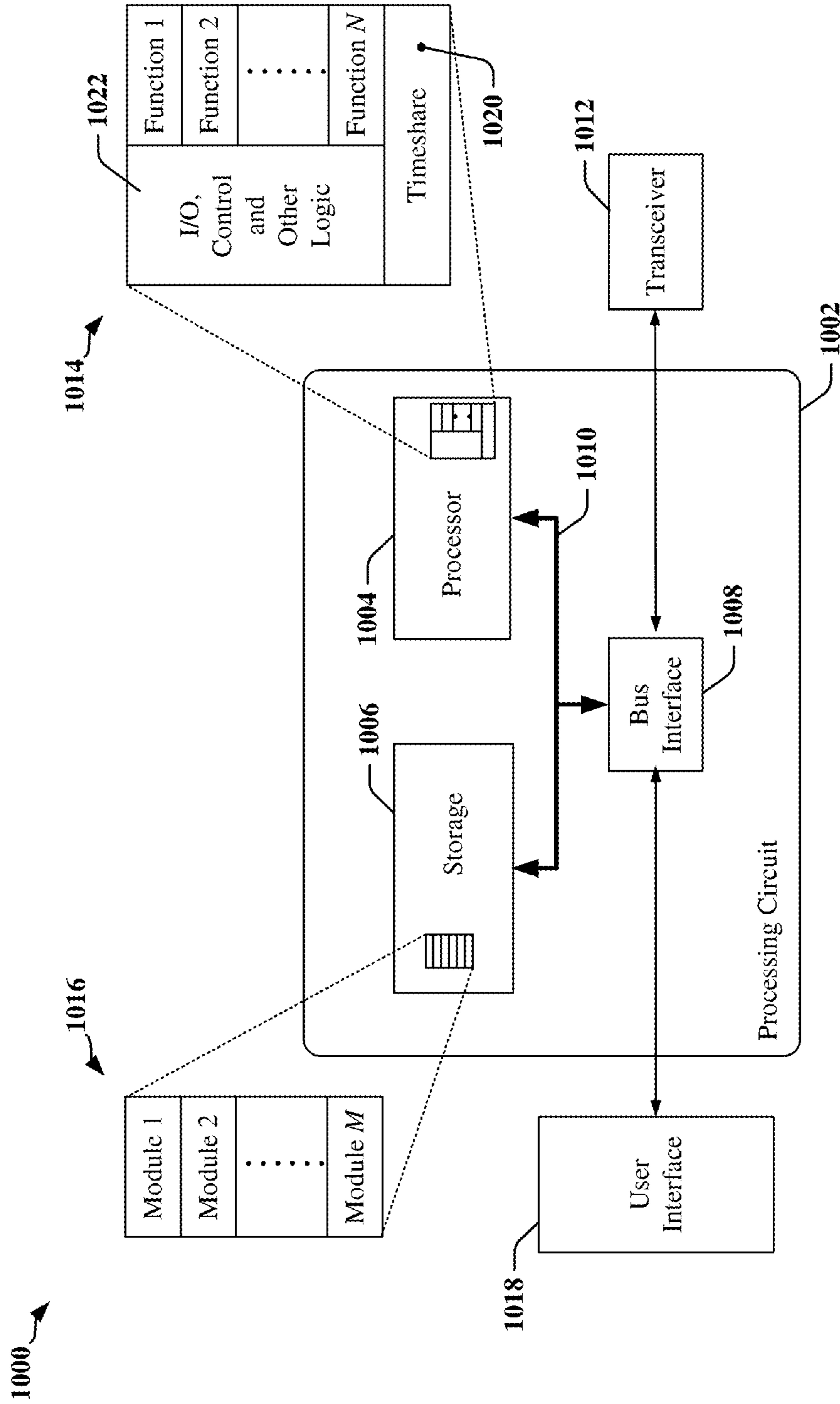
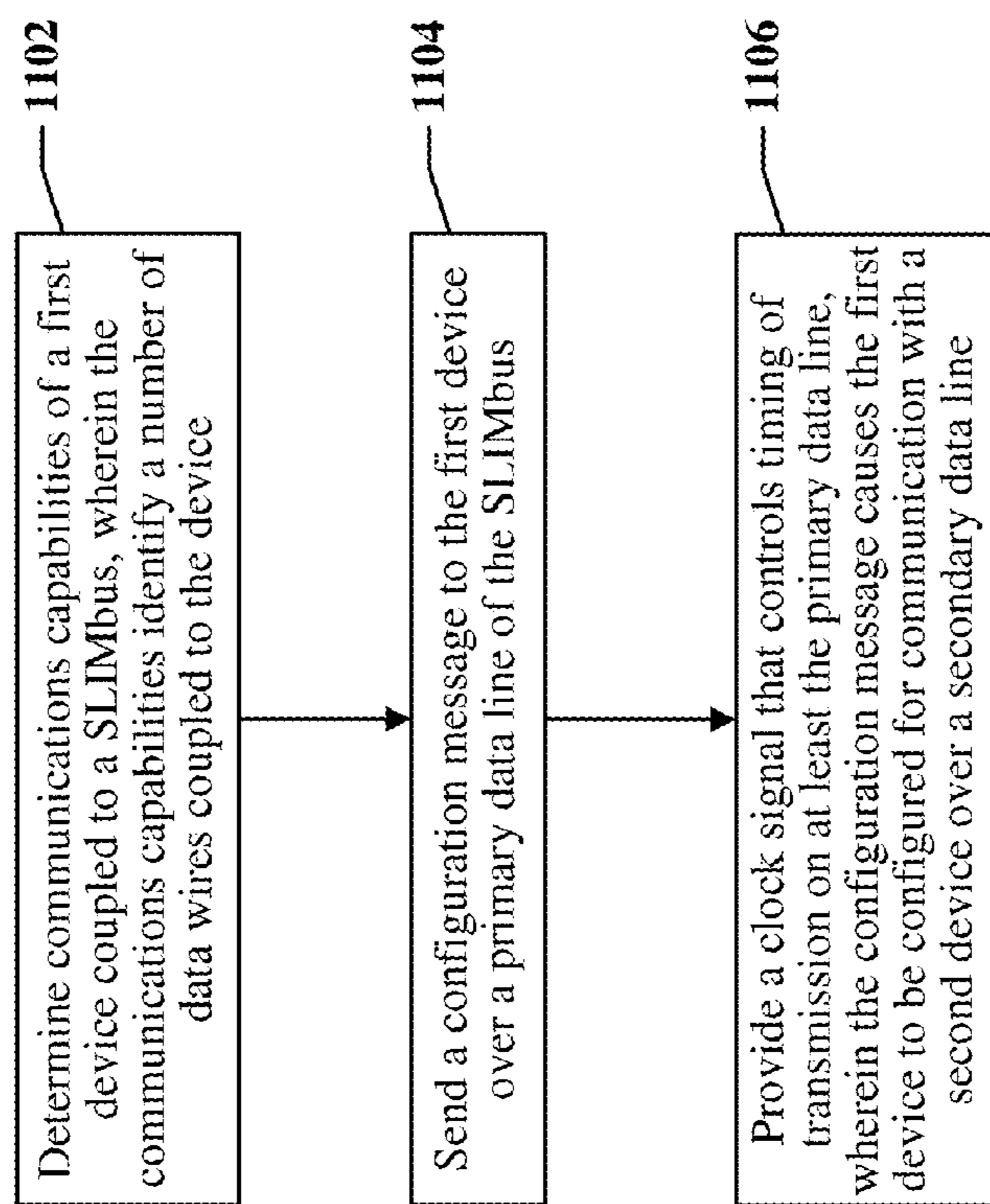


FIG. 10

1100 ↗



**FIG. 11**



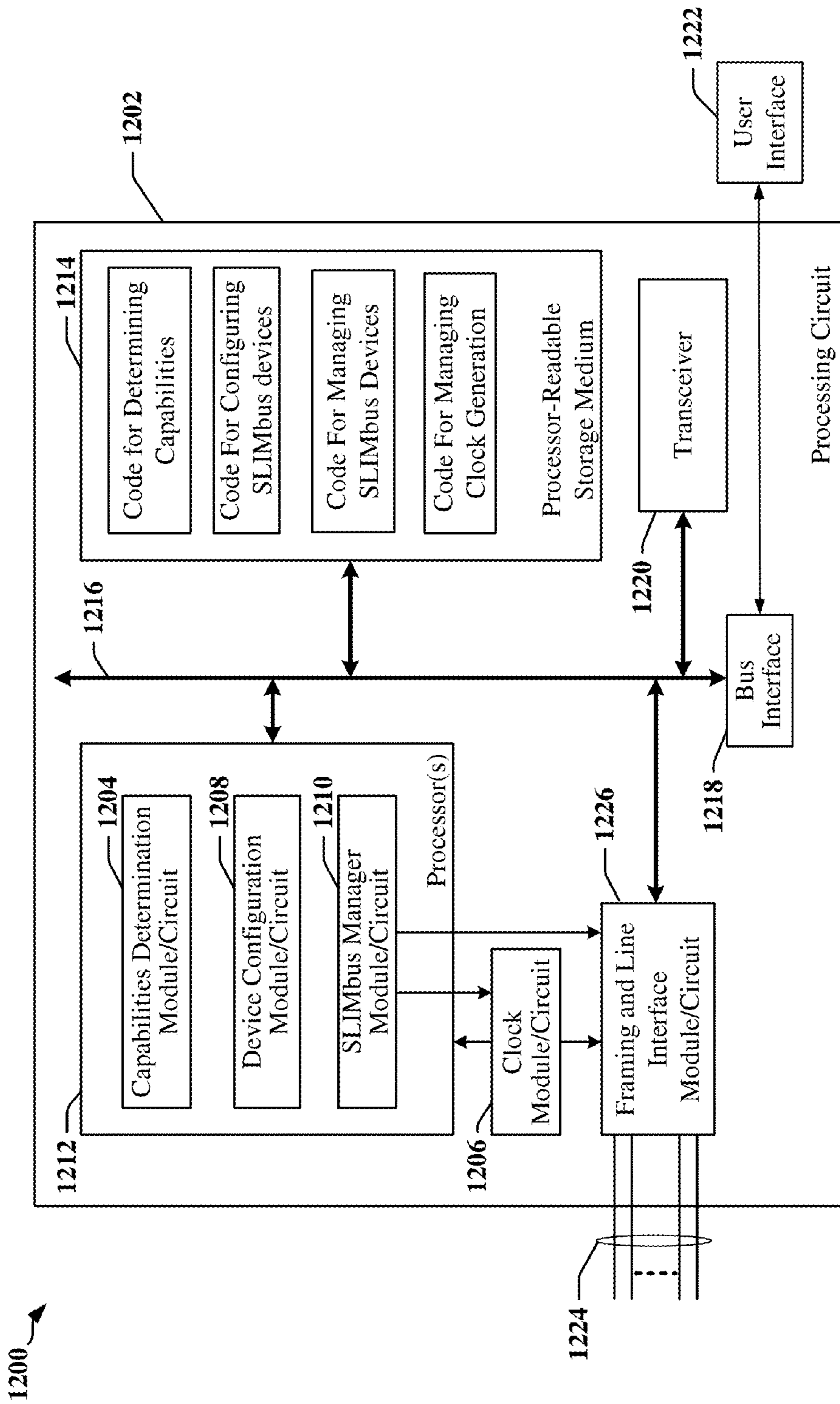
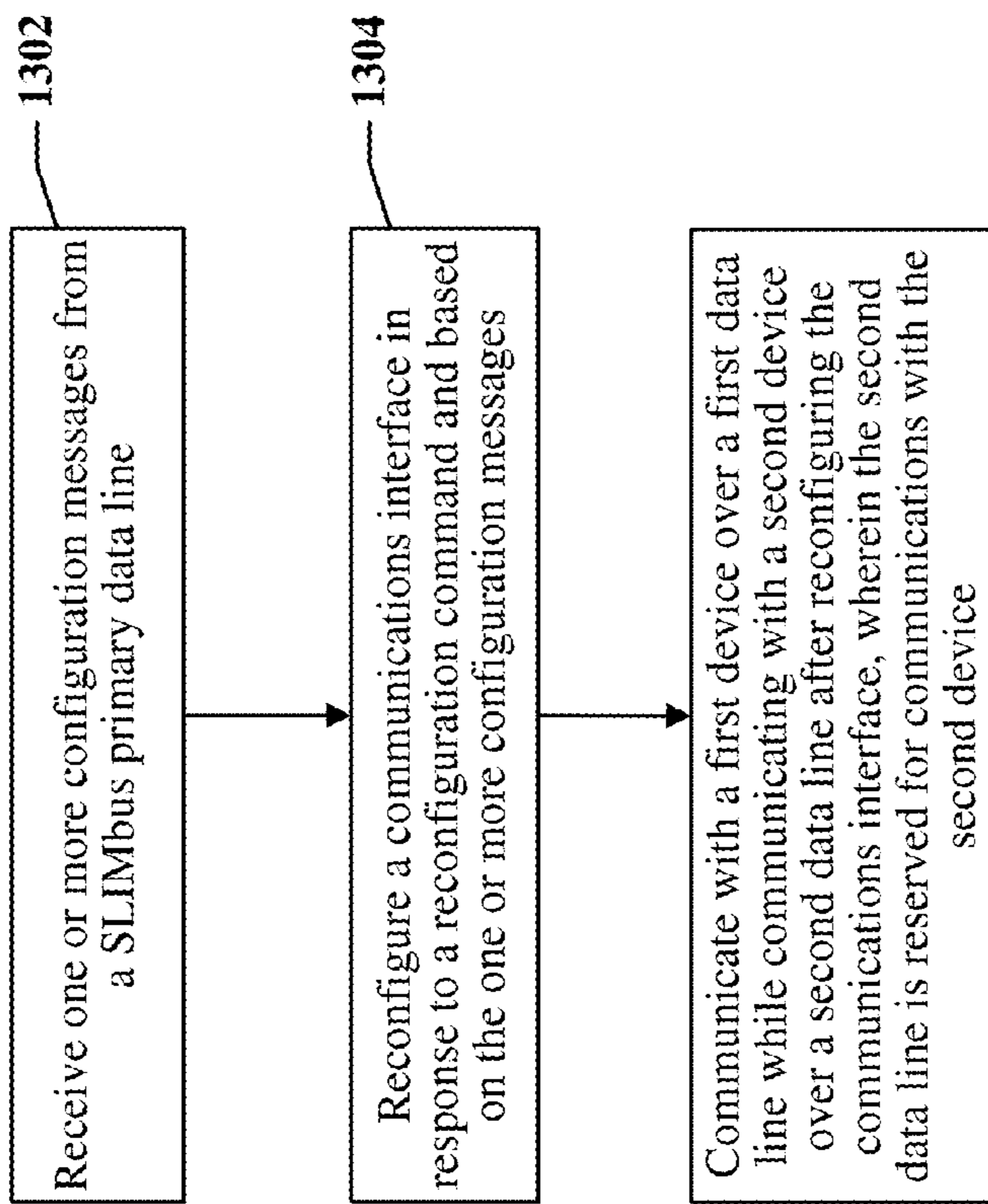


FIG. 12

1300 →



**FIG. 13**

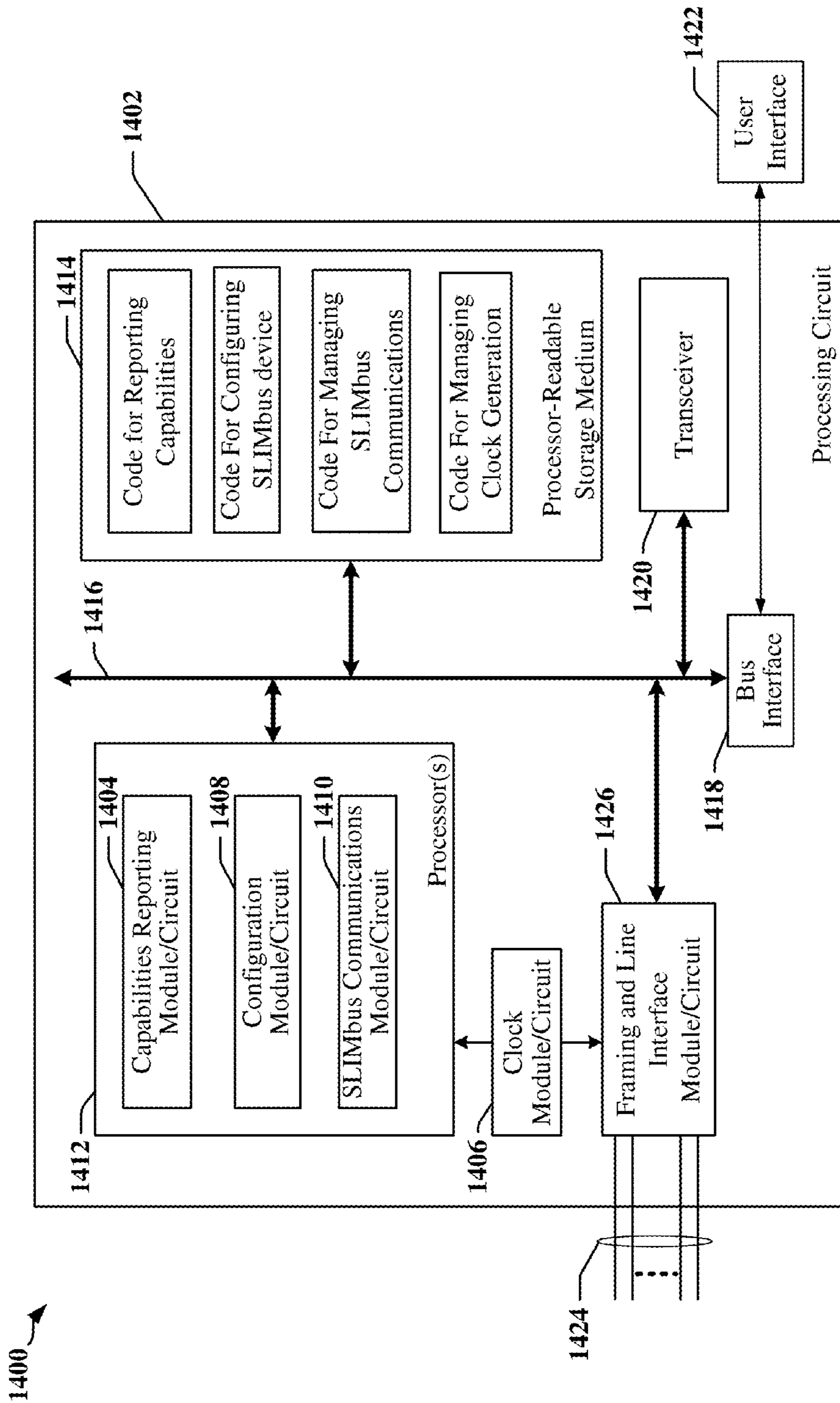


FIG. 14



**SYSTEM AND METHOD OF SENDING DATA  
VIA ADDITIONAL SECONDARY DATA  
LINES ON A BUS**

CROSS-REFERENCE TO RELATED  
APPLICATIONS

The present application for patent claims priority to Provisional Application No. App. No. 61/904,133, entitled "System And Method Of Sending Data Via Additional Secondary Data Lines On A Bus" filed Nov. 14, 2013, which is assigned to the assignee hereof and hereby expressly incorporated by reference herein.

BACKGROUND

Field

The present disclosure relates generally to data communications interfaces, and more particularly, to data communications links provided between multiple devices.

Background

Manufacturers of mobile devices, such as cellular phones, may obtain components of the mobile devices from various sources, including different manufacturers. For example, an application processor in a cellular phone may be obtained from a first manufacturer, while the display for the cellular phone may be obtained from a second manufacturer. The application processor and a display or other device may be interconnected using a standards-based or proprietary physical interface.

In one example, the serial low-power inter-chip media bus (SLIMbus) standard is a communication bus standard that is well-suited for use in portable computing devices such as mobile phones. In accordance with the SLIMbus standard, components may be connected by a single SLIMbus data line and a single clock line. However, new generations of devices attached to a SLIMbus require ever-increasing bandwidth and throughput for applications that process and communicate audio and video data.

Accordingly, there is a need to increase communication bandwidths available between components of mobile devices and other apparatus.

SUMMARY

Embodiments disclosed herein provide systems, methods and apparatus that can improve the operation of SLIMbus communications links. The communications link may be deployed in apparatus such as a mobile terminal having multiple Integrated Circuit (IC) devices.

In certain aspects of the disclosure, a data communications method includes determining communications capabilities of a first device coupled to a SLIMbus, sending a configuration message to the first device over a primary data line of the SLIMbus, and providing a clock signal that controls timing of transmission on at least the primary data line. The communications capabilities may include information identifying a number of data wires supported by or coupled to the device. The configuration message may cause the first device to be configured for communication with a second device over a secondary data line. The first device may be configured to communicate with the second device using a SLIMbus protocol. The first device may be configured to communicate with the second device using a non-SLIMbus protocol. The secondary data line may connect the first device with the second device independently of the SLIMbus. Communications on the secondary data line may

be synchronized using the clock signal. The configuration message may include a framing message.

In one aspect, the method may include allocating a plurality of communications channels in time slots on both the primary data line and the secondary data line data. The first device may communicate with the second device using one of the plurality of communications channels.

In one aspect, the configuration message includes control information reserving the secondary data line for communications between the first device and the second device. The secondary data line may be one of a plurality of secondary data lines of the SLIMbus. The control information may be generated by a SLIMbus manager provided on a third device. The third device may be restricted to communicating over the primary data line.

In one aspect, the method includes sending configuration messages over the primary data line to a plurality of devices, and transmitting a reconfiguration command to the one or more devices. The reconfiguration command may cause each of the plurality of devices to adopt a configuration in accordance with at least one configuration message. At least one configuration message sent over the primary data line may be addressed to a predefined set of devices. The first device may be configured to relay at least one configuration message sent over the primary data line to a third device.

In certain aspects of the disclosure, an apparatus includes means for determining communications capabilities of a first device coupled to a SLIMbus, means for sending configuration and framing messages to the first device over a primary data line of the SLIMbus, and means for providing a clock signal that controls timing of transmission on at least the primary data line. The communications capabilities may identify a number of data wires coupled to the device. The first device may be configured to communicate with a second device over a secondary data line.

In certain aspects of the disclosure, an apparatus includes a processing circuit configured to determine communications capabilities of a first device coupled to a SLIMbus, send a configuration message and/or a framing message to the first device over a primary data line of the SLIMbus, and provide a clock signal that controls timing of transmission on at least the primary data line. The communications capabilities may identify a number of data wires coupled to the device. The first device may be configured to communicate with a second device over a secondary data line.

In certain aspects of the disclosure, a processor-readable storage medium may be encoded with one or more instructions which, when executed by at least one processing circuit, cause the at least one processing circuit to determine communications capabilities of a first device coupled to a SLIMbus, send a configuration message and/or a framing message to the first device over a primary data line of the SLIMbus, and provide a clock signal that controls timing of transmission on at least the primary data line. The communications capabilities may identify a number of data wires coupled to the device. The first device may be configured to communicate with a second device over a secondary data line.

In certain aspects of the disclosure, a communications method includes receiving one or more configuration messages from a SLIMbus primary data line, reconfiguring a communications interface in based on the one or more configuration messages and in response to a reconfiguration command, and communicating with a first device over a first data line while communicating with a second device over a second data line. The second data line may be reserved for communications with the second device. The first data line



may include the SLIMbus primary data line or a SLIMbus secondary data line. The second data line may be a SLIMbus secondary data line that employs a framing and control configuration used by the SLIMbus primary data line. The framing and control configuration may define a root clock frequency. The framing and control configuration may define gearing and is used to calculate a frame boundary. In some instances, communications on the second data line may be controlled by a non-SLIMbus protocol.

In one aspect, the method may include reporting communications capabilities information to a manager device. The configuration messages may be generated in response to the communications capabilities information.

In certain aspects of the disclosure, an apparatus includes means for receiving one or more configuration messages from a SLIMbus primary data line, means for reconfiguring a communications interface based on the one or more configuration messages and in response to a reconfiguration command, and means for communicating with a first device over a first data line while communicating with a second device over a second data line. The second data line may be reserved for communications with the second device.

In certain aspects of the disclosure, an apparatus includes a processing circuit configured to receive one or more configuration messages from a SLIMbus primary data line, reconfigure a communications interface based on the one or more configuration messages and in response to a reconfiguration command, and communicate with a first device over a first data line while communicating with a second device over a second data line. The second data line may be reserved for communications with the second device.

In certain aspects of the disclosure, a processor-readable storage medium stores or maintains one or more instructions. The instructions may be executed by at least one processing circuit and may cause the at least one processing circuit to receive one or more configuration messages from a SLIMbus primary data line, reconfigure a communications interface based on the one or more configuration messages and in response to a reconfiguration command, and communicate with a first device over a first data line while communicating with a second device over a second data line. The second data line may be reserved for communications with the second device.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts an apparatus employing a data link between IC devices that selectively operates according to one of a plurality of available standards.

FIG. 2 illustrates a simplified system architecture for an apparatus employing a data link between IC devices.

FIG. 3 illustrates a SLIMbus communications link provided between SLIMbus components.

FIG. 4 illustrates a device adapted to communicate over a SLIMbus communications link.

FIG. 5 illustrates a first network of devices connected by a SLIMbus communications link.

FIG. 6 illustrates scheduling on a SLIMbus communications link.

FIG. 7 illustrates a second network of devices connected by a SLIMbus communications link that has multiple data lines and a manager.

FIG. 8 illustrates a third network of devices connected by a SLIMbus communications link that has multiple data lines.

FIG. 9 illustrates a fourth network of devices connected by a configurable SLIMbus communications link that has multiple data lines including shared and private data lines.

FIG. 10 is a block diagram illustrating an example of an apparatus employing a processing system that may be adapted according to certain aspects disclosed herein.

FIG. 11 is a first flow chart illustrating a method for data communications on a SLIMbus according to certain aspects disclosed herein.

FIG. 12 illustrates an example of an apparatus that can connect to a configurable SLIMbus communications link and perform the method of FIG. 11 in accordance with certain aspects disclosed herein.

FIG. 13 is a second flow chart illustrating a method for data communications on a SLIMbus according to certain aspects disclosed herein.

FIG. 14 illustrates an example of an apparatus that can connect to a configurable SLIMbus communications link and perform the method of FIG. 13 in accordance with certain aspects disclosed herein.

#### DETAILED DESCRIPTION

Various aspects are now described with reference to the drawings. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more aspects. It may be evident, however, that such aspect(s) may be practiced without these specific details.

As used in this application, the terms “component,” “module,” “system” and the like are intended to include a computer-related entity, such as, but not limited to hardware, firmware, a combination of hardware and software, software, or software in execution. For example, a component may be, but is not limited to being, a process running on a processor, a processor, an object, an executable, a thread of execution, a program and/or a computer. By way of illustration, both an application running on a computing device and the computing device can be a component. One or more components can reside within a process and/or thread of execution and a component may be localized on one computer and/or distributed between two or more computers. In addition, these components can execute from various computer readable media having various data structures stored thereon. The components may communicate by way of local and/or remote processes such as in accordance with a signal having one or more data packets, such as data from one component interacting with another component in a local system, distributed system, and/or across a network such as the Internet with other systems by way of the signal.

Moreover, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or.” That is, unless specified otherwise, or clear from the context, the phrase “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, the phrase “X employs A or B” is satisfied by any of the following instances: X employs A; X employs B; or X employs both A and B. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless specified otherwise or clear from the context to be directed to a singular form.

Certain aspects of the invention may be applicable to communications links deployed between electronic devices that may include subcomponents of an apparatus such as a telephone, a mobile computing device, a wearable computing device, a media player, a gaming device, an appliance, automobile electronics, avionics systems, etc. FIG. 1 illustrates one example of a wireless communications device 100 that may employ a communications link between IC devices. In one example, the wireless communications



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device **100** may include a wireless communication device that communicates through an RF interface with a radio access network, a core access network, the Internet and/or another network. The wireless communications device **100** may include a communications transceiver **106** operably coupled to a processing circuit **102**. The processing circuit **102** may include one or more IC devices, such as an application-specific IC (ASIC) **108**. The ASIC **108** may include one or more processing devices, logic circuits, and so on. The processing circuit **102** may include and/or be coupled to processor readable storage such as a memory **112** that may maintain instructions and data that may be executed by processing circuit **102**. The processing circuit **102** may be controlled by one or more of an operating system and an application programming interface (API) layer **110** that supports and enables execution of software modules residing in storage media, such as the memory **112** of the wireless device. The memory **112** may include read-only memory (ROM) or random-access memory (RAM), electrically erasable programmable ROM (EEPROM), flash cards, or any memory device that can be used in processing systems and computing platforms. The processing circuit **102** may include or have access to a local database **114** that can maintain operational parameters and other information used to configure and operate the wireless communications device **100**. The local database **114** may be implemented using one or more of a database module, flash memory, magnetic media, EEPROM, optical media, tape, soft or hard disk, or the like. The processing circuit **102** may also be operably coupled to internal and/or external devices, which may include an antenna **122**, a display system **124**, and operator controls such as buttons **128**, **130** and/or a keypad **126**, among other components. In some examples, the display system **124** may include a touchscreen component.

FIG. 2 is a block schematic diagram **200** illustrating certain aspects of an apparatus such as the wireless communications device **100** of FIG. 1, a wireless mobile computing device, a mobile telephone, a wireless telephone, a notebook computer, a tablet computing device, a media player, a gaming device, a wearable computing device, an appliance, or the like. The apparatus **200** may include a plurality of IC devices **202** and **230** that exchange data and control information through a communications link **220**. The communications link **220** may be used to connect two or more IC devices **202** and **230** that are located in close proximity to one another, or that are physically located in different parts of the apparatus **200**. In one example, the communications link **220** may be provided on a chip carrier, substrate or circuit board that carries the IC devices **202** and **230**. In another example, a first IC device **202** may be located in a keypad section of a smartphone or flip-phone while a second IC device **230** may be located in a display section of the flip-phone, on a touchscreen display panel, etc. In another example, a portion of the communications link **220** may include a cable or optical connection.

The communications link **220** may have multiple individual data links **222**, **224** and **226**. One communications link **226** may include bidirectional connectors, and may operate in time division, half-duplex, full-duplex, or other modes. One or more communications links **222** and **224** may include unidirectional connectors. The communications link **220** may be asymmetrically configured, providing higher bandwidth in one direction and/or between different IC devices **202**, **230**. In one example, a first communications link **222** between the two IC devices **202**, **230** may be referred to as a forward link **222** while a second communications link **224** between the two IC devices **202**, **230** may

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be referred to as a reverse link **224**. In another example, a first IC device **202** may operate or be designated as a host, manager, master and/or transmitter, while one or more other IC devices **230** may be designated as a client, slave and/or receiver, even if both IC devices **202** and **230** are configured to transmit and receive on the communications link **222**. In one example, a data link **222** may operate at a higher data rate when communicating data from a first IC device **202** to a second IC device **230** than a data link provided between the first IC device **202** and a third IC device (not shown).

The IC devices **202** and **230** may each include a general-purpose processor or other processing and/or computing circuit or device **206**, **236** adapted to cooperate with various circuits and modules in order to perform certain functions disclosed herein. The IC devices **202**, **230** may perform different functions and/or support different operational aspects of the apparatus **200**. A plurality of IC devices, including the IC devices **202** and **230** may include modems, transceivers, display controllers, user interface devices, Bluetooth interface devices, audio/visual systems, digital-to-analog converters, analog-to-digital converters, memory devices, processing devices, and so on. In one example, the first IC device **202** may perform core functions of the apparatus **200**, including maintaining wireless communications through a wireless transceiver **204** and an antenna **214**, while the second IC device **230** may support a user interface that manages or operates a display controller **232**, and/or may control operations of a camera or video input device using a camera controller **234**. Other features supported by one or more of the IC devices **202** and **230** may include a keyboard, a voice-recognition component, application processors, and various input or output devices. The display controller **232** may have circuits and software drivers that support displays such as a liquid crystal display (LCD) panel, touch-screen display, indicators and so on. The storage media **208** and **238** may include transitory and/or non-transitory storage devices adapted to maintain instructions and data used by the respective processors **206** and **236**, and/or other components of the IC devices **202** and **230**. Communication between each processor **206**, **236** and its corresponding storage media **208** and **238** and other modules and circuits may be facilitated by one or more bus **212** and **242**, respectively.

Different links **222**, **224** and or **226** may be capable of transmitting at comparable speeds or at different speeds, where speed may be expressed as data transfer rate and/or clocking rates. Data rates may be substantially the same or differ by orders of magnitude, depending on the application. In some applications, a single bidirectional link **226** may support communications between the first IC device **202** and the second IC device **230**. The forward link **222** and/or reverse link **224** may be configurable to operate in a bidirectional mode and the forward and reverse links **222** and **224** may share the same physical connections, connectors and/or wires. In one example, the communication link **220** may be operated to communicate control, command and other information between the first IC device **202** and the second IC device **230** in accordance with an industry or other standard.

Industry standards may be application specific. In one example, the Mobile Industry Processor Interface (MIPI) standard defines physical layer interfaces, including the SLIMbus interface, that may be used to provide an interface between an application processor IC device **202** and an IC device **230** that supports functional elements and modules of a mobile device, including a camera, display, media player, etc.



FIG. 3 is a simplified block diagram of a system 300 that illustrates a SLIMbus communications link 310 provided between SLIMbus components 304 and 306. The SLIMbus communications link 310 may include a plurality of SLIMbus data lines 312, 314 deployed between the SLIMbus components 304, 306. As further described herein, the SLIMbus communications link 310 may be adapted or configured to provide more than two data lines as desired or as needed to obtain a desired bandwidth and throughput on the SLIMbus communication bus 310.

The SLIMbus communications link 310 may include a SLIMbus clock line 316 that has a frequency selected by dividing a “root clock” frequency. In some example, the root clock may have a frequency of 28 MHz or more. In some examples, the frequency of the SLIMbus clock line 316 may be selected by using one of 10 available clock gears. Clock gears may divide the clock frequency by powers of 2. In one example, the SLIMbus clock line 316 may have a frequency ( $f_{CLK}$ ) calculated using the equation:

$$f_{CLK} = \frac{f_{ROOT}}{2^{G-10}}$$

where  $f_{ROOT}$  is the frequency of the root clock and G is the gear selected. In this configuration, the maximum clock frequency is selected when G=10 and the maximum clock frequency is equal to the frequency of the root clock.

The system 300 may include a host 302 coupled to a first SLIMbus component 304. The first SLIMbus component 304 may be coupled to a second SLIMbus component 306 using the SLIMbus communications link 310, which may include one or more of a first SLIMbus data line 312 and a second SLIMbus data line 314. The second SLIMbus component 306 may be coupled to a third component 308, which may include a SLIMbus component or a non-SLIMbus device.

The host 302 may include a processing circuit that has one or more of a digital signal processor (DSP), a central processing unit (CPU), a graphics processing unit (GPU), a microprocessor, or any combination thereof. The host 302 may include a mobile station modem (MSM), a mobile data modem (MDM), a radio frequency transceiver (RTR), an application processor (APQ), or any combination thereof. The first SLIMbus data line 312 may support a first bandwidth and the second SLIMbus data line 314 may support a second bandwidth. In one example, the first SLIMbus data line 312 and the second SLIMbus data line 314 may be clocked at the same frequency, and the first SLIMbus data line 312 and the second SLIMbus data line 314 may carry data at the same data rate. In another example, the first SLIMbus data line 312 may have a greater bandwidth than the second SLIMbus data line 314. In another example, the second SLIMbus data line 314 may have a greater bandwidth than the first SLIMbus data line 312, when the second SLIMbus data line 314 and the first SLIMbus data line 312 are clocked at different rates. In the latter example, the first bandwidth may be 28 megabits per second (Mbps) and the second bandwidth may be greater than 28 Mbps. Throughput on one or more of the first SLIMbus data line 312 and the second SLIMbus data line 314 may be decreased when the first SLIMbus data line 312 and/or the second SLIMbus data line 314 carries control information.

Each of the plurality of SLIMbus data lines 312, 314 may be a bi-directional data line. In some examples, one SLIMbus data line 312 or 314 may be a bi-directional data line

while the second SLIMbus data line 314 or 312 may be a unidirectional data line. As used herein, a bi-directional data line may be a data line that is capable of sending data in different directions between two or more devices. Further, each of the plurality of SLIMbus data lines 312, 314 may be utilized to transmit data associated with a different power level. For example, the first SLIMbus data line 312 may be utilized for low power traffic while the second SLIMbus data line 314 may be utilized for higher power traffic. A power budget may be in effect for certain types of traffic. Power consumption may be managed or controlled in certain applications by configuring one or more of a transmit clock frequency, an encoding scheme used to encode data for transmission on the SLIMbus data line 312 or 314, data compression ratios, type of data encoded, and so on.

During operation, data may be sent from the first SLIMbus component 304 to the second SLIMbus component 306. As used herein, data may include audio data, non-audio data, pulse-code modulation (PCM) audio data, Sony Philips Digital Interface (SPDIF) data, High Definition Audio (HDA) data, professional audio data (i.e., 192 kHz, 24 bit as used in Dolby Surround 5.1/7.1, and certain Roland Music systems), or any combination thereof. The first SLIMbus component 304 may send data on one or more SLIMbus data lines selected from the plurality of SLIMbus data lines 312, 314. For example, the data may be sent via the first SLIMbus data line 312, the second SLIMbus data line 314, or any combination thereof.

In accordance with certain aspects disclosed herein, the first SLIMbus component 304 may send data in parallel over multiple SLIMbus data lines 312 and 314 or send the data serially over a single SLIMbus data line 312 or 314. Whether the data is sent in parallel or serially may depend on factors such as a size of the data, a clock frequency of at least one SLIMbus data line, a compatibility of the data with the SLIMbus data transmission protocol, a priority of the data, a quality of service requirement, or based on any combination of these and/or other factors.

The first SLIMbus component 304 may send data in parallel using the first SLIMbus data line 312 and the second SLIMbus data line 314. In one example, the data may be divided into two portions, and the portions may be transmitted concurrently, or substantially concurrently, over the SLIMbus data lines 312 and 314. Upon receipt, the data may be interleaved and/or concatenated. In another example, the data may be divided into two portions and the first SLIMbus component 304 may send the data serially over one of the first SLIMbus data line 312 and the second SLIMbus data line 314. In some instances, the two portions of data may be transmitted sequentially over either the first SLIMbus data line 312 or the second SLIMbus data line 314. The data may be sent in accordance with a SLIMbus data transmission protocol, a time-division transmission protocol, or a non time-division transmission protocol.

According to certain aspects disclosed herein, the third device 308 may be configured to be compatible with a configuration that supports the plurality of SLIMbus data lines 312, 314, as described herein. For example, the third device 308 may be configured to receive data from the first component 304 over the plurality of SLIMbus data lines 312, 314. Certain data sent to the third device 308 may be transmitted in accordance with a non-SLIMbus protocol, which may be a non-time division protocol or a time-division protocol other than the SLIMbus data transmission protocol.

According to certain aspects disclosed herein, data transmitted over each SLIMbus data line 312, 314 may corre-



spond to different SLIMbus components. For example, the first and second components **304**, **306** may be configured to receive and transmit data using the first SLIMbus data line **312** and the SLIMbus clock line **316**, while third and fourth SLIMbus components may be configured to receive and transmit data using the second SLIMbus data line **314** and the SLIMbus clock line **316**. The same SLIMbus clock line **316** may control timing and rates of data transfer between different components or sets of components that each use a different SLIMbus data line **312**, **314**.

A SLIMbus device may be restricted or configured for connection to a single SLIMbus data line **312**, **314**. In some examples, one or more SLIMbus components **304**, **306** may be connected to a plurality of available SLIMbus data lines **312**, **314**, and may be connected to a single SLIMbus clock line **316**. In addition, devices configured for compatibility with multiple SLIMbus data lines may coexist in the system **300** with legacy devices that support only one SLIMbus data line.

FIG. 4 illustrates an apparatus **400** adapted to communicate over a SLIMbus communications link **310**. In the example, the apparatus **400** includes an IC device **402** that can be adapted to communicate with one or more other IC devices (not shown) using a plurality of SLIMbus data lines **312**, **314** and the SLIMbus clock line **316**.

The IC device **402** may correspond to a functional component implemented using one or more modules or circuits, such as a processing circuit or device, a coder/decoder (CODEC), an input device, an output device, etc. The IC device **402** may include a SLIMbus component **304** or **306** illustrated in FIG. 3, in addition to system level device logic **404**. In one example, the IC device **402** operates as a SLIMbus component **304** and the host **302** of FIG. 3 includes the system level device logic **404**.

In one example, the IC device **402** may include a direct memory access (DMA) layer **408**, a SLIMbus device layer **410**, a transport protocol layer **412**, a frame layer **414**, and a physical layer **416**. The DMA layer **408** may include or be implemented by a processing circuit such as a first finite state machine (FSM) **418**, a sequencer or other processing circuit or device. The DMA layer **408** may include a plurality of pipes, including a first pipe **420a** and a second pipe **420b**. The plurality of pipes may include additional pipes up to an nth pipe **420n**. The plurality of pipes may be configured as one or more message channels that transmit messages such as data messages and/or user-defined configuration messages.

The SLIMbus device layer **410** may be a generic device layer, an interface device layer, a framer device layer, a manager device layer, or any combination thereof. The SLIMbus device layer **410** may include a processing circuit such as a second FSM **422**, one or more First-In-First-Out (FIFO) buffers and one or more ports, which may also be referred to as message ports. In one example, a first FIFO buffer **424a**, a second FIFO buffer **424b**, and other FIFO buffers up to an nth FIFO buffer **424n**, a first port (Port-0) **426a**, a second port (Port-1) **426b**, up to an nth port (Port-n) **426n**. Each port **426a-426n** may be connected to a corresponding FIFO buffer **424a-424n**. For example, the first port **426a** may be connected to the first FIFO buffer **424a**, the second port **426b** may be connected to the second FIFO buffer **424b** and so on, until the nth port **426n** which may be connected to the nth FIFO buffer **424n**.

In some examples, each port **426a-426n** may be coupled to two FIFO buffers **424a-424n**, which may enable and/or support bi-directional data transfer capabilities of each individual port **424a-424n**. For example, the first port **426a** may

be connected to the first FIFO buffer **424a** and the second FIFO buffer **424b**. In addition, the ports may support asynchronous connections thereby making more ports available to the apparatus **400**. It will be appreciated that the use of dual-FIFO ports may effectively double an overall number of available ports in a system, because a single pair of ports may be used for bi-directional communication between two devices instead of using a dedicated pair of uplink ports and a dedicated pair of downlink ports.

The frame layer **414** may generate a switch select signal **432** and may include a first multiplexer **434** and a second multiplexer **436**. The first multiplexer **434** may be associated with data transmission **428** and the second multiplexer **436** may be associated with data reception **430**. The switch select signal **432** may cause the first multiplexer **434** to transmit data via the first SLIMbus data line **312**, the second SLIMbus data line **314**, or any combination thereof. Alternatively or additionally, the switch select signal **432** may cause the second multiplexer **436** to receive data via the first SLIMbus data line **312**, the second SLIMbus data line **314**, or any combination thereof.

In some configurations, the frame layer **414** may include a single multiplexer **434** or **436**. For example, the IC device **402** may include two frame layers **414**, each including a single multiplexer **434**, **436**. In another example, the transport protocol layer **412** may include the first multiplexer **434** and the second multiplexer **436**, and an additional SLIMbus clock line may be used. However, because the additional SLIMbus clock line may consume more power than a SLIMbus data line, implementations involving multiple SLIMbus clock lines may be avoided to reduce power consumption. In one example, a SLIMbus clock line **316** may account for 60-70% of total power consumption attributable to the SLIMbus connection **310**.

FIG. 5 is a block diagram illustrating one example of an apparatus **500** that employs a SLIMbus communications link **552** with multiple data lines **556**, **558**. In this example, the apparatus **500** may include devices **502**, **504** and **506** that have dual data line capable SLIMbus components, and at least one device **508** that includes one or more single data line capable SLIMbus components. Each of the devices **502**, **504**, **506** and **508** may be provided in, or include an IC device. Each of the devices **502**, **504**, **506** and **508** may cooperate with one or more other IC devices or other circuits that may be disposed upon a chip carrier, within a single package, or on a circuit board, for example.

In one example, the first device **502** (Device A) may function as an application processor that includes a master or manager **550**, a first port (Port-0) **512**, a second port (Port-1) **514**, and a third port (Port-2) **516**. The first device **502** may also include a framer **518** and a configuration register **510** that maintains configuration parameters and other information related to the operation of the first device **502**. The framer **518** may correspond to, and/or implement certain functions of the frame layer **414** of FIG. 4, for example. The second device **504** (Device B) may be an audio CODEC and may include a first port **522**, a second port **524**, a third port **526**, a framer **528** and a configuration register **520**. The third device **506** (Device C) may be a data modem that includes a first port **532**, a second port **534**, a framer **538** and a configuration register **530**. The fourth device **508** (Legacy Device D) may be a legacy device, such as an input or output device (including, for example, a device related to a speaker or a microphone) that is manufactured without multiple data line SLIMbus capabilities. The fourth device **508** may include a first port **542**, a second port **544**, a framer **548** and a configuration register **540**.



In operation, the manager **550** may configure communications within the apparatus **500** based on a determination of the capabilities of the SLIMbus components of each of the devices **502**, **504**, **506** and **508**. The configuration typically takes account of the data line capabilities (single, double, multiple) of the constituent devices **502**, **504**, **506** and **508**. The manager **550** may be implemented as some combination of hardware and software. In one example, the manager **550** may be implemented in Device A **502**, and may include or employ a processing circuit, a sequencer, a state machine, software and firmware, or any combination thereof. The manager **550** may determine the configuration of SLIMbus components during an enumeration process. For example, during enumeration, the manager **550** may determine that the first device **502**, the second device **504**, and the third device **506** have dual data line capable SLIMbus components and that the fourth device **508** has a single data line capable SLIMbus component.

The manager **500** may determine the capabilities of each SLIMbus component by querying one or more of the configuration registers **510**, **520**, **530**, **540**, which maintain information identifying the capabilities of corresponding SLIMbus components or devices **502**, **504**, **506** and/or **508**. In one example, information related to SLIMbus component capabilities may be predefined by a device manufacturer. In another example, the information related to SLIMbus component capabilities may be configured by a system integrator.

In some instances, the capabilities of each SLIMbus component may be determined based on communication with a high-level operating system (HLOS). For example, an HLOS associated with a particular device **502**, **504**, **506** and/or **508** may provide a configuration file, and may exchange capability bits for each device. The HLOS may use a look-up table and/or query a configuration database for capability information.

In some examples, the capabilities of each SLIMbus component may be determined through dedicated messaging, including information transmitted through a dedicated message channel. In one example, the dedicated message channel is provided using one or more time slots on a primary data line **556**, which may be connected to all SLIMbus devices **502**, **504**, **506**, **506**. In some examples, one or more user-defined messages may be transmitted between SLIMbus components, where the user-defined messages include data indicating whether the SLIMbus components are configurable or configured for single data line, dual data line, or capable of supporting another number of SLIMbus data lines.

FIG. **6** includes scheduling diagrams **600**, **620** that illustrate timing of transmissions associated with a SLIMbus communications link in accordance with certain aspects disclosed herein. The scheduling diagrams **600** and **620** illustrate different examples of scheduling applicable to the apparatus **500** of FIG. **5**. The first scheduling diagram **600** relates to an example of scheduling when a common messaging and framing is used for a plurality of SLIMbus data lines **556** and **558**, while the second scheduling diagram **620** relates to an example of scheduling when each of a plurality of SLIMbus data lines **556** and **558** uses individualized messaging and framing configurations.

The first scheduling diagram **600** relates to an example in which data may be communicated from a first SLIMbus component **502**, **504**, **506** and/or **508** to one or more ports of a second SLIMbus component **502**, **504**, **506** and/or **508** using time-division multiplexing (TDM). In a TDM scheme, a sequence of primary data frames **602** may be transmitted

on a primary data line **556**. A plurality of sequential time intervals (slots) may be defined by the TDM scheme. In one example, a slot may be defined as four contiguous bits. Bandwidth allocation for various data organizations, from 4-bit data to 32-bit data (or more) can be accomplished by grouping the 4-bit Slots. The duration, function and frequency of occurrence of each slot may be configured according to application needs and operational considerations. A frame may be defined as including 192 contiguous slots. Each primary data frame **602** typically includes framing slots **604** and **608** that precede one or more data slots **608a-608d** and **610a-610d**, respectively. In one example, the first slot of each frame may be defined as a control slot, which may carry a 4-bit frame sync symbol and other slots may carry framing information. A superframe may be defined as a transmission that includes 8 contiguous frames. The timing of a superframe may be defined by the timing of slots in the constituent frames that make up the superframe, and the superframe transmission rate may be dynamically configured through selection of a combination of the root frequency and gearing.

The data slots **608** and **610** may be used to carry the payload data of one or more messages. The data slots **608** and **610** may be allocated to one or more channels, where each channel carries data between a source SLIMbus component **502**, **504**, **506** and/or **508** and a destination SLIMbus component **502**, **504**, **506** and/or **508**. For example, a first data slot **608a** and **610a** may be allocated to a first channel for communications between a first port **512** of the first device (Device A) **502** and a second port **534** of the third device (Device C) **506**, data slots **608c** and **610c** may be allocated to carry a second channel for communications between a first port **522** of the second device (Device B) **504** and a second port **544** of the fourth device (Device D) **508**. The remaining slots **608b/610b** and **608d/610d** may be allocated for other channels, and/or may be placed in an idle state.

A sequence of secondary data frames **612** may be concurrently or contemporaneously transmitted on the secondary SLIMbus data line **558**. The secondary data frames **612** may be apportioned into data slots **614**, **616a-616c**, **618a-618c** and **620** corresponding in time to data slots of the primary data frames **602**. In the first example **600**, the first data slots **614** and **620** in the secondary data frames **612** may be idled or otherwise unused and the framing information received in data slots **604** and **606** of the primary data frames **602** may be used to configure the secondary data frames **612**. In this configuration, additional bandwidth may be defined for channels defined on the primary data frames **602**, and/or additional channels may be defined on the secondary data frames **612**. In one example, data transmitted in the first channel may use one or more data slots **616a-616c** of the secondary data frames **612** in addition to the data slots **608a** and **610a** allocated in the primary data frames **602**. In another example, data transmitted from the second port **514** of Device A **502** to the second port **524** of Device B **504** may be sent in a third channel that is allocated one or more data slots **616b** and **618b** of the secondary data frames **612**.

Data may be transmitted between a pair of devices **502**, **504**, **506** and/or **508** using two or more physical SLIMbus lines **556** and **558** and in multiple data slots **608**, **610**. Data sent over multiple SLIMbus data lines **556** and **558** and/or in multiple data slots **608**, **610** may be time interleaved upon receipt. The data slots in the primary data frames **602** and in the secondary data frames **604** may be associated with a common clock cycle, configured by information provided in the framing slot **604**, **606**. As a result, the data may be sent



over the first and second SLIMbus data lines **556** and **558** synchronously, in parallel, simultaneously, and/or substantially simultaneously.

During the framing slots **604** and **606**, the second SLIMbus data line **558** may be idle. In some conventional implementations, certain data slots **616c** and **618c** of the secondary data frames **604** may be idled when corresponding data slots **608c**, **608d**, **610c** and **610d** are used for communications involving a device **508** that is not dual data line capable. According to certain aspects disclosed herein, other devices **502**, **504** and **506** may attempt to establish private data communications channels utilizing the idle data slots **616c**, **618c** in the secondary data frames **612** by scheduling communication between themselves. It will be appreciated that this may result in systems in which the existence of communications channels on a second SLIMbus data line **558** is "hidden" from non-participating device **502**, **504** or **506**. Moreover, the existence of the secondary data line **558** may be concealed from legacy devices **508** that are compatible with a single SLIMbus data line. In some instances, the manager **550** may be responsible for scheduling and configuring data rates using a hidden second SLIMbus data line **558** even if the managing device **550** of the apparatus **500** is implemented on a legacy device **508** incapable of receiving communications over the second SLIMbus data line **558**.

The second scheduling diagram **620** illustrates an example of data communications in which the data slots **634**, **636** of the secondary data frames **632**, which correspond to the framing slots **626**, **630** of the primary data frames **622**, can be allocated to communications channels between SLIMbus components **502**, **504**, and/or **506** that are capable of receiving communications over the second SLIMbus data line **558**. Bandwidth and throughput may be maximized for implementations where messaging and framing is coordinated for all SLIMbus data lines **556**, **558**. In some examples, data slots of the primary data frames **622** and the secondary data frames **632** may correspond to different clock cycles or bus cycles, and may have different timing. Therefore, in addition to sending data synchronously or in parallel as described with respect to the first scheduling diagram **600**, data may be transmitted asynchronously between SLIMbus component **502**, **504**, **506** and/or **508**.

The SLIMbus component **502**, **504**, **506** and/or **508** may be configured to permit transmission from a single source SLIMbus component **502**, **504**, **506** and/or **508** to multiple destination SLIMbus component **502**, **504**, **506** and/or **508**. For example, data may be transmitted from the second port **524** of Device B **504** to the second port **514** of Device A **502**, and to the first port **532** of Device C **506** over the first SLIMbus data line **556** and the second SLIMbus data line **558** during the selected data slots **608**, **610**, **624** and **628**. Scheduling for data communications between two or more SLIMbus ports **512**, **514**, **516**, **522**, **524**, **526**, **532**, **534**, **542** and/or **544** over one or more SLIMbus data lines **556** and **558** may be effected using a common bus cycle based on a centrally controlled clock.

Certain aspects of conventional SLIMbus communications links may limit the ability of the technology to respond to demands for increased bandwidth and throughput. The rate of the data traffic that is needed for certain high bandwidth applications requires that a root frequency to be increased to 24.576 MHz or a higher multiple thereof in order to maintain bus efficiency and enable the continued use of isochronous transfer protocols. Isochronous data transfer can be used for the transmission of real-time data, including audio and video data. Isochronous transfer or transport

protocols may be used to meet delivery requirements that require information to be delivered within a certain time period. However, increased root frequencies can lead to slew rate issues that affect the ability of a receiver to decode transmitted data.

FIG. 7 is a block diagram illustrating an example of an apparatus **700** that employs an expanded SLIMbus communications link **720** with a primary data line **724** and one or more (n) secondary data lines **726**. The apparatus **700** may include devices **702**, **704**, **706** and **708** which have multiple data line capable SLIMbus components. The devices **702**, **704**, **706** and **708** may be provided in a single IC device, or may include one or more IC devices coupled to other circuits and disposed upon a chip carrier, circuit board or within a single package, for example. According to certain aspects disclosed herein, communications channels may be implemented using some combination of the primary data line **724** and one or more of the secondary data lines **726** that carry messages in compliance with SLIMbus specifications, and/or one or more of the secondary data lines **726** configured to carry messages on non-SLIMbus communications channels. In some examples, secondary data lines **726** may be configured to provide a decentralized or private SLIMbus communications channels to further improve available bandwidth and throughput within the apparatus **700**.

In some instances, a plurality of the n secondary data lines **726** may be used for directly connecting two or more devices **702**, **704**, **706** and **708**. In one example, one or more of the n secondary data lines **726** may be reserved for communications between two or more of the devices **702**, **704**, **706** and **708**, while at least the primary data line **724** is monitored and/or used for communication by all of the devices **702**, **704**, **706** and **708**.

Timing of each of the secondary data lines **726** may be configured to follow the same relationship as the clock line and the primary data line **724**. In one example, secondary data lines **726** do not carry any control information and all devices **702**, **704**, **706** and **708** can maintain bus synchronization based on signaling associated with the primary data line **724**. Accordingly, there may be no necessity to synchronize the n secondary data lines **726** with one another, or to handle loss of synchronization on one of the secondary data lines **726**.

Each device **702**, **704**, **706** and **708** may include a framer module in the Frame Layer **712**, **714**, **716** and **718**. A management module (Manager) **710** may be operated on one of the devices **702**, **704**, **706** or **708**.

FIG. 8 illustrates an example of a SLIMbus communications link **820** that connects a plurality of multiple SLIMbus data line capable devices **802**, **804**, **806** and at least one single data line capable SLIMbus device **808**. In this example, a manager **810** may be active on the device or component **808** that supports only a primary data line **824**, although the manager **810** may control configuration and operation of multiple secondary data lines **826** and a clock signal **822** used by other devices **802**, **804**, **806**.

FIG. 9 is a block diagram **900** illustrating an example of an apparatus in which communications between a plurality of IC devices **902**, **904**, **906**, **908**, **910** and **912** is facilitated by a flexibly configurable data communications link **928**. In the example, the plurality of the IC devices **902**, **904**, **906**, **908**, **910** and **912** may be configured to communicate according to a SLIMbus protocol. In one example, some or all of the plurality of the IC devices **902**, **904**, **906**, **908**, **910** and **912** may transmit, receive and/or monitor communications on at least a primary SLIMbus data line **932**. Some or all of the plurality of the IC devices **902**, **904**, **906**, **908**, **910**



and **912** may receive timing information from the SLIMbus clock **930**. Accordingly, each of the IC devices **902**, **904**, **906**, **908**, **910**, and **912** may include a framer **914**, **916**, **918**, **920**, **922**, and **924** configured to receive and/or transmit information according to SLIMbus protocols and timing. The information may include configuration and timing information generated by a manager component **926**. For example, the configuration and timing information may include setup and other parameters maintained and/or reported by each of the plurality of the IC devices **902**, **904**, **906**, **908**, **910** and **912**, and timeslot allocations provided by the manager **926**.

In one example, the manager **926** may receive configuration parameters reported by some or all of the IC devices **902**, **904**, **906**, **908**, **910** and **912** indicating availability of single-line or multi-line SLIMbus data transmission and reception capabilities. In another example, one or more of the IC devices **902**, **904**, **906**, **908**, **910** and **912** may report the presence of a hidden secondary data line **936**, **938** that may be used for private or direct communications channels between two or more devices. The private or direct communications channels may be operated using SLIMbus protocols synchronized with the SLIMbus clock **930** and/or may be operated using a different time-division or non-time division protocol that may be synchronized based on the SLIMbus clock **930**, at the frame level, or not synchronized with SLIMbus operations.

In another example, the manager **926** may allocate communications channels on secondary data lines **934**, **936** and **938** for the use of pairs or groups of the plurality of the IC devices **902**, **904**, **906**, **908**, **910** and **912**. Accordingly, dedicated secondary data lines **936** and **938** may be connected to all of the IC devices **902**, **904**, **906**, **908**, **910** and **912**, but monitored and/or used by only a few of the IC devices **902**, **904**, **906**, **908**, **910** and **912**. For example, the manager **926** may configure the data link such that a secondary data line **936** is available for the sole use of a first pair of IC devices **910** and **912**, while a second secondary data line **938** is restricted or otherwise available for the sole use of a second pair of IC devices **904** and **906**.

In each of these examples, configuration, timing and global multicast communications (i.e., between all of the IC devices **902**, **904**, **906**, **908**, **910** and **912**) may be restricted to the primary data line **932**. The primary data line **932** and a common secondary data line **934** may be used to carry communications channels between those IC devices **902**, **904**, **906**, **910** and **912** that are capable of multi-line communication and that are connected to the common secondary data line **934**. The common secondary data line **934** may be used for multicast messages directed to any subset of the IC devices **902**, **904**, **906**, **910** and **912** that is connected to the common secondary data line **934**.

The clock signal **930** may serve as a master clock used to synchronize one or more clocks that provide timing for signaling on corresponding data lines **932**, **934**, **936** and **938**. In some examples, signaling on each data line **932**, **934**, **936** and/or **938** may be derived from or synchronized to the SLIMbus clock **930**.

The data link **928** may be implemented as a physical bus having multiple data lines **930**, **932**, **934**, **936**, **938**, whereby the IC devices **902**, **904**, **906**, **908**, **910** and **912** may selectively be physically connected to some configuration of the data lines **930**, **932**, **934**, **936**, **938**. Thus, the first private channel between IC devices **910** and **912** may be implemented by physically connecting the IC devices **910** and **912** to the S1 secondary data line **936**, where the remaining IC devices **902**, **904**, **906** and **908** are not connected to the S1

secondary data line **936**. Alternatively or additionally, a private channel may be constructed by causing only the subject pair of IC devices **910** and **912** to connect, monitor and/or otherwise use the S1 secondary data line **936**. The channelization of a common data line **932**, **934** according to a time-division protocol allows the common data line **932**, **934** to be used as a private channel for a larger number of IC devices **902**, **904**, **906**, **908**, **910** and **912**, which are configured to use the common primary data line **932** or secondary data line **934** (for example) only during an allocated time slot.

The data communications link **928** may be adapted or configured to implement a broad range of topologies. Available topologies may include point-to-point secondary data lines **936**, **938** provided privately between pairs of the IC devices **902**, **904**, **906**, **908**, **910** and **912** and/or multipoint secondary data lines **936**, **938** provided privately between trios and other combinations of the IC devices **902**, **904**, **906**, **908**, **910** and **912**.

In some topologies, legacy single data line capable IC devices **908** may be provisioned with a signal line **840** configured to communicate with one or more other IC devices **902**, **904**, **906**, **910** and **912** through a secondary data line **934**, **936** or **938**. For example, the legacy IC device **908** may be coupled to the S1 secondary data line **936** (or to any other secondary data line **934**, **938**) using a different protocol and/or type of physical connection and may receive configuration information indirectly through another multiple data line capable IC device **910** and/or **912** as well as through the primary data line **932**. The legacy IC device **908** may be configured and operated as a slave to the multiple data line capable IC device **910** and/or **912** or the multiple data line capable IC device **910** and/or **912** may pass through configuration and other information from the manager **926**.

A hierarchical network may be constructed that optimizes communications based on priority, data rates, quality of service requirements and profiles of sources and/or destinations for communications associated with the IC devices **902**, **904**, **906**, **908**, **910** and **912**. In one example, communications over the S1 secondary data line **936** may be clocked at lower rates than data is clocked on the primary data line **932** or the common secondary data line **934**, and the connection of the legacy IC device **908** through another IC device **910** or **912** may improve overall system throughput. In another example, the legacy IC device **908** may be connected to a secondary data line **934**, **936**, or **938** that operates according to a lower rate clock than the primary data line **932**, such that the primary data line **932** can operate at an optimal or highest clock rate while the legacy IC device **908** can communicate at a rate consistent with its capabilities.

The data communications link **928** may be configured by a process consistent with SLIMbus protocols. For example, the manager **926** may transmit configuration and/or programming messages to each IC device **902**, **904**, **906**, **908**, **910** and/or **912**. The configuration and/or programming messages may define the topology, clock rates and communication channel allocations to timeslots and data lines from the perspective of each IC device **902**, **904**, **906**, **908**, **910** and **912**. After configuration/programming messages have been transmitted to each IC device **902**, **904**, **906**, **908**, **910** and **912**, a "RECONFIG\_NOW" message may be transmitted to each IC device **902**, **904**, **906**, **908**, **910** and **912**. In response to receiving the "RECONFIG\_NOW" message, each of the IC devices **902**, **904**, **906**, **908**, **910** and **912** may begin operating in accordance with the most recently received configuration/programming message at the next



appropriate frame boundary. In some examples, the “RECONFIG\_NOW” message may be used to synchronize configuration/programming of the SLIMbus components.

Configuration can be defined independently for individual IC devices **902, 904, 906, 908, 910** and **912**, pairs of IC devices **902, 904, 906, 908, 910** and **912**, or other sized groups or sets of IC devices **902, 904, 906, 908, 910** and **912**. Configuration information may be provided in multiple stages, such that one or more IC devices **902, 904, 906, 908, 910** and **912** may be configured individually and may receive additional configuration or reconfiguration of certain parameters in one or more group configuration/programming messages. Furthermore, a “RECONFIG\_NOW” message may be used to provoke selective response by one or more IC devices **902, 904, 906, 908, 910** and **912** based on which devices or pairs, trios and other groups or sets of IC devices **902, 904, 906, 908, 910** and **912** are addressed by the “RECONFIG\_NOW” message.

As shown in FIG. 6, framing and control slots **634** and **636** may be used for data transmission on a secondary data line **934, 936** and/or **938**, while framing and control information is transmitted in corresponding slots **626** and **630** on the primary data line **932**. In some examples, the slots **634** and **636** on a secondary data line **934, 936** and/or **938** may be reserved for framing and control information when a downstream IC device **908** relies on an upstream IC device **910** or **912** to relay framing and control information from the manager **926**. In some instances, the framing and control information transmitted on the secondary data line **934, 936** and/or **938** may be reformatted before transmission in order to accommodate legacy IC devices **908**.

In some examples, the framing and control information transmitted on the secondary data line **934, 936** and/or **938** may be reformatted when the secondary data line **934, 936** and/or **938** is operated in accordance with a non-SLIMbus protocol. One or more secondary data lines **934, 936** and/or **938** may be reserved for non-SLIMbus data channels. In such instances, a modified framing and startup process may be employed for secondary data lines **934, 936** and/or **938** that are reserved for non-SLIMbus data channels.

The general startup and framing procedures used for SLIMbus data lines **932, 934, 936** and/or **938** may be adapted for use with non-SLIMbus data channels. In one example, these general startup framing procedures include causing the secondary data lines **934, 936** and/or **938** to become inactive whereby any component that is not in an operational state refrains from driving a secondary data line **934, 936** and/or **938**, such that data on the secondary data lines **934, 936** and/or **938** is only transmitted/received after a data channel has been configured by the Manager **926**.

Secondary data lines **934, 936** and/or **938** may start in a low logic state to ensure proper Non-Return-to-Zero Inverted (NRZI) encoding and decoding at each of the SLIMbus devices **902, 904, 906, 908, 910** and/or **912**. In a SLIMbus interface, all SLIMbus devices **902, 904, 906, 908, 910** and/or **912** are required to listen to the primary data line **932** to ensure that synchronization and control information is captured. The SLIMbus infrastructure for a data communications link **928** that has multiple secondary data lines **934, 936** and **938** can remain identical or comparable to a single data line SLIMbus implementation, regardless of the ability of connected SLIMbus devices **902, 904, 906, 908, 910** and/or **912** to support secondary lines.

A secondary data line **934, 936** and/or **938** may have a topology that is different from the topology of the primary data line **932**, or from any other secondary data line **934, 936** and/or **938**. The manager **926** may correctly configure the

data communications link **928** and allocate data channels when the manager **926** is aware of the capabilities and desired configuration of the SLIMbus devices **902, 904, 906, 908, 910** and/or **912**. All data channels allocated by the manager **926** may be transmitted and/or received on a single data line **932**.

In one example, a data communications link **928** may be configured such that secondary data lines **934, 936** and **938** operate in parallel with the primary data line **932**. The secondary data lines **934, 936** and **938** typically do not include control spaces such as time slots used for framing and control purposes. Accordingly, control space collisions are prevented on a secondary data line **934, 936** and/or **938**, where a collision may refer to the result of a simultaneous transmission by two or more devices on a data bus that is operated using a multi-drop bus topology. Framing and control messages may be transmitted in channels on the primary data line **932**. Secondary data lines **934, 936** and/or **938** may maintain the same control characteristics as the primary data line **932**, including the root clock frequency, clock gear settings and so on. A superframe boundary, frame count, and slot counts may be calculated and maintained by components/devices based on signaling on the primary data line **932**. Therefore, the SLIMbus devices **902, 904, 906, 908, 910** and/or **912** cannot typically lose superframe or Frame sync on a secondary line if it maintains synchronization with the primary data line **932**. When the data communications link **928** is configured for a parallel distribution, channel allocation may be restricted to an even number of time slots.

One or more dedicated information elements of a control/framing field may be assigned for configuring SLIMbus devices **902, 904, 906, 908, 910** and **912** to support additional secondary data lines. In one example, such information elements may be used for enumerating secondary data lines **934, 936** and/or **938**.

The SLIMbus protocol may be adapted to include additional control and framing messages when multiple secondary data lines **934, 936, 938** are used. In one example, the additional control and framing messages may include “NEXT\_DEFINE\_DATA\_LINE,” “NEXT\_EXTENDED\_DEFINE\_CHANNEL,” and/or other messages that may be used to allocate and/or configure data line numbers and channels. Legacy IC devices **908** that cannot support multiple data lines may respond with a negative acknowledgement (NACK) in response to such additional commands.

FIG. 10 is a conceptual diagram **1000** illustrating a simplified example of a hardware implementation for an apparatus employing a processing circuit **1002** that may be configured or adapted according to certain aspects disclosed herein. In accordance with various aspects of the disclosure, an element, or any portion of an element, or any combination of elements as disclosed herein may be implemented using the processing circuit **1002**. The processing circuit **1002** may include one or more processors **1004** that are controlled by some combination of hardware and software modules. Examples of processors **1004** include microprocessors, microcontrollers, digital signal processors (DSPs), field programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, sequencers, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functionality described throughout this disclosure. The one or more processors **1004** may include specialized processors that perform specific functions, and that may be configured, augmented or controlled by one of the software modules **1016**. The one or more processors **1004** may be configured through a combi-



nation of software modules **1016** loaded during initialization, and further configured by loading or unloading one or more software modules **1016** during operation.

In the illustrated example, the processing circuit **1002** may be implemented with a bus architecture, represented generally by the bus **1010**. The bus **1010** may include any number of interconnecting buses and bridges depending on the specific application of the processing circuit **1002** and the overall design constraints. The bus **1010** links together various circuits including the one or more processors **1004**, and storage **1006**. Storage **1006** may include memory devices and mass storage devices, and may be referred to herein as computer-readable media and/or processor-readable media. The bus **1010** may also link various other circuits such as timing sources, timers, peripherals, voltage regulators, and power management circuits. A bus interface **1008** may provide an interface between the bus **1010** and one or more transceivers **1012**. A transceiver **1012** may be provided for each networking technology supported by the processing circuit. In some instances, multiple networking technologies may share some or all of the circuitry or processing modules found in a transceiver **1012**. Each transceiver **1012** provides a means for communicating with various other apparatus over a transmission medium. Depending upon the nature of the apparatus, a user interface **1018** (e.g., keypad, display, speaker, microphone, joystick) may also be provided, and may be communicatively coupled to the bus **1010** directly or through the bus interface **1008**.

A processor **1004** may be responsible for managing the bus **1010** and for general processing that may include the execution of software stored in a computer-readable medium that may include the storage **1006**. In this respect, the processing circuit **1002**, including the processor **1004**, may be used to implement any of the methods, functions and techniques disclosed herein. The storage **1006** may be used for storing data that is manipulated by the processor **1004** when executing software, and the software may be configured to implement any one of the methods disclosed herein.

One or more processors **1004** in the processing circuit **1002** may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software modules, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, algorithms, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. The software may reside in computer-readable form in the storage **1006** or in an external computer readable medium. The external computer-readable medium and/or storage **1006** may include a non-transitory computer-readable medium. A non-transitory computer-readable medium includes, by way of example, a magnetic storage device (e.g., hard disk, floppy disk, magnetic strip), an optical disk (e.g., a compact disc (CD) or a digital versatile disc (DVD)), a smart card, a flash memory device (e.g., a "flash drive," a card, a stick, or a key drive), a random access memory (RAM), a read only memory (ROM), a programmable ROM (PROM), an erasable PROM (EPROM), an electrically erasable PROM (EEPROM), a register, a removable disk, and any other suitable medium for storing software and/or instructions that may be accessed and read by a computer. The computer-readable medium and/or storage **1006** may also include, by way of example, a carrier wave, a transmission line, and any other suitable medium for transmitting software and/or instructions that may be accessed and read by a computer. Computer-readable medium and/or the storage **1006** may reside

in the processing circuit **1002**, in the processor **1004**, external to the processing circuit **1002**, or be distributed across multiple entities including the processing circuit **1002**. The computer-readable medium and/or storage **1006** may be embodied in a computer program product. By way of example, a computer program product may include a computer-readable medium in packaging materials. Those skilled in the art will recognize how best to implement the described functionality presented throughout this disclosure depending on the particular application and the overall design constraints imposed on the overall system.

The storage **1006** may maintain software maintained and/or organized in loadable code segments, modules, applications, programs, etc., which may be referred to herein as software modules **1016**. Each of the software modules **1016** may include instructions and data that, when installed or loaded on the processing circuit **1002** and executed by the one or more processors **1004**, contribute to a run-time image **1014** that controls the operation of the one or more processors **1004**. When executed, certain instructions may cause the processing circuit **1002** to perform functions in accordance with certain methods, algorithms and processes described herein.

Some of the software modules **1016** may be loaded during initialization of the processing circuit **1002**, and these software modules **1016** may configure the processing circuit **1002** to enable performance of the various functions disclosed herein. For example, some software modules **1016** may configure internal devices and/or logic circuits **1022** of the processor **1004**, and may manage access to external devices such as the transceiver **1012**, the bus interface **1008**, the user interface **1018**, timers, mathematical coprocessors, and so on. The software modules **1016** may include a control program and/or an operating system that interacts with interrupt handlers and device drivers, and that controls access to various resources provided by the processing circuit **1002**. The resources may include memory, processing time, access to the transceiver **1012**, the user interface **1018**, and so on.

One or more processors **1004** of the processing circuit **1002** may be multifunctional, whereby some of the software modules **1016** are loaded and configured to perform different functions or different instances of the same function. The one or more processors **1004** may additionally be adapted to manage background tasks initiated in response to inputs from the user interface **1018**, the transceiver **1012**, and device drivers, for example. To support the performance of multiple functions, the one or more processors **1004** may be configured to provide a multitasking environment, whereby each of a plurality of functions is implemented as a set of tasks serviced by the one or more processors **1004** as needed or desired. In one example, the multitasking environment may be implemented using a timesharing program **1020** that passes control of a processor **1004** between different tasks, whereby each task returns control of the one or more processors **1004** to the timesharing program **1020** upon completion of any outstanding operations and/or in response to an input such as an interrupt. When a task has control of the one or more processors **1004**, the processing circuit is effectively specialized for the purposes addressed by the function associated with the controlling task. The timesharing program **1020** may include an operating system, a main loop that transfers control on a round-robin basis, a function that allocates control of the one or more processors **1004** in accordance with a prioritization of the functions, and/or an



interrupt driven main loop that responds to external events by providing control of the one or more processors 1004 to a handling function.

FIG. 11 is a flowchart illustrating a communications method according to certain aspects of the invention. The method may be performed by a device 902 that includes a manager circuit or module 926. At step 1102, the device 902 may determine communications capabilities of a first device coupled to a SLIMbus. The communications capabilities may identify a number of data wires coupled to the first device.

At step 1104, the device 902 may send a configuration message and/or a framing message to the first device over a primary data line of the SLIMbus. The configuration message may include control information reserving the secondary data line for communications between the first device and the second device. The secondary data line may be one of a plurality of secondary data lines of the SLIMbus. The control information may be generated by a SLIMbus manager provided on a third device. The third device may be restricted to communicating over the primary data line. In some examples, the control information may be generated by a SLIMbus manager provided on one of the first and second devices. The configuration message may include a framing message.

In an aspect of the disclosure, the configuration message may cause the first device to be configured for communication with a second device over a secondary data line. In one example, the first device may be configured to communicate with the second device using a SLIMbus protocol. In another example, the first device may be configured to communicate with the second device using a non-SLIMbus protocol. The secondary data line may connect the first device with the second device independently of the SLIMbus.

At step 1106, the device 902 may provide a clock signal that controls timing of transmission on at least the primary data line. Communications on the secondary data line may be synchronized using the clock signal.

In an aspect of the disclosure, a plurality of communications channels in time slots on both the primary data line and the secondary data line data may be allocated. The first device may communicate with the second device using one of the plurality of communications channels.

In an aspect of the disclosure, configuration messages sent over the primary data line to a plurality of devices. The reconfiguration command may cause each of the plurality of devices to adopt a configuration in accordance with at least one configuration message. At least one configuration message sent over the primary data line may be addressed to a predefined set of devices.

In an aspect of the disclosure, the first device may be configured to relay at least one configuration message sent over the primary data line to a third device that is not connected to the primary data line.

FIG. 12 is a conceptual diagram illustrating an example of a hardware implementation for an apparatus 1200 employing a processing circuit 1202. In this example, the processing circuit 1202 may be implemented with a bus architecture, represented generally by the bus 1216. The bus 1216 may include any number of interconnecting buses and bridges depending on the specific application of the processing circuit 1202 and the overall design constraints. The bus 1216 links together various circuits including one or more processors, represented generally by the processor 1212, and computer-readable media, represented generally by the processor-readable storage medium 1214. The bus

1216 may also link various other circuits such as timing sources, timers, peripherals, voltage regulators, and power management circuits. A bus interface 1218 provides an interface between the bus 1216 and a transceiver 1220. The transceiver 1220 may include a bus interface that provides a means for communicating with various other apparatus over a transmission medium. Depending upon the nature of the apparatus, a user interface 1222 (e.g., keypad, display, speaker, microphone, joystick) may also be provided. One or more clock circuits or modules 1206 may be provided within the processing circuit 1202 or controlled by processing circuit 1202 and/or one or more processors 1212. In one example, the clock circuits or modules 1206 may include one or more crystal oscillators, one or more phase-locked loop devices, and/or one or more configurable clock trees.

The processor 1212 is responsible for managing the bus 1216 and general processing, including the execution of software stored on the processor-readable storage medium 1214. The software, when executed by the processor 1212, causes the processing circuit 1202 to perform the various functions described supra for any particular apparatus. The processor-readable storage medium 1214 may be used for storing data that is manipulated by the processor 1212 when executing software.

In one configuration, the apparatus 1200 may be coupled to a SLIMbus 1224 and may include modules or circuits 1204 for determining communications capabilities of other devices coupled to the SLIMbus 1224, modules or circuits 1210, 1226 adapted or configured to send configuration and framing messages to one or more devices over a primary data line of the SLIMbus 1224, and clock generating modules or circuits 1206 that provide a clock signal that controls timing of transmissions on at least the primary data line of the SLIMbus 1224. Configuration and SLIMbus management modules or circuits 1208, 1210 may cooperate to define and/or allocate a plurality of communications channels in time slots on a primary data line and/or a secondary data line of the SLIMbus 1224. In one example, the apparatus 1200 may include interface module and/or circuits 1226 that implements framing and control for the SLIMbus 1224. In some instances, a manager module or circuit may 1210 may control the operation of various circuits and modules 1204, 1206, 1208, and may be responsible for configuring the SLIMbus 1224 and other apparatus connected to the SLIMbus 1224.

FIG. 13 is a flowchart illustrating a communications method according to certain aspects of the invention. The method may be performed by a device 910, 912 that supports communication over a plurality of data lines 932, 934, 936, 940. At step 1302, the device 910, 912 may receive one or more configuration messages from a SLIMbus primary data line.

At step 1304, the device 910, 912 may reconfigure a communications interface in response to a reconfiguration command and based on the one or more configuration messages.

At step 1306, the device 910, 912 may communicate with a first device over a first data line while communicating with a second device over a second data line. The second data line may be reserved for communications with the second device. The first data line may include the SLIMbus primary data line or a SLIMbus secondary data line. The second data line may be a SLIMbus secondary data line that employs a framing and control configuration used by the SLIMbus primary data line. The framing and control configuration may define a root clock frequency. The framing and control configuration may define gearing and is used to calculate a



frame boundary. Communications on the second data line may be controlled by a non-SLIMbus protocol.

In an aspect of the disclosure, communications capabilities information may be reported to a manager device. The configuration messages may be generated in response to the communications capabilities information.

FIG. 14 is a conceptual diagram illustrating an example of a hardware implementation for an apparatus 1400 employing a processing circuit 1402. In this example, the processing circuit 1402 may be implemented with a bus architecture, represented generally by the bus 1416. The bus 1416 may include any number of interconnecting buses and bridges depending on the specific application of the processing circuit 1402 and the overall design constraints. The bus 1416 links together various circuits including one or more processors, represented generally by the processor 1412, and computer-readable media, represented generally by the processor-readable storage medium 1414. The bus 1416 may also link various other circuits such as timing sources, timers, peripherals, voltage regulators, and power management circuits. A bus interface 1418 provides an interface between the bus 1416 and a transceiver 1420. The transceiver 1420 may include a bus interface that provides a means for communicating with various other apparatus over a transmission medium. Depending upon the nature of the apparatus, a user interface 1422 (e.g., keypad, display, speaker, microphone, joystick) may also be provided. One or more clock circuits or modules 1406 may be provided within the processing circuit 1402 or controlled by processing circuit 1402 and/or one or more processors 1412. In one example, the clock circuits or modules 1406 may include one or more crystal oscillators, one or more phase-locked loop devices, and/or one or more configurable clock trees.

The processor 1412 is responsible for managing the bus 1416 and general processing, including the execution of software stored on the processor-readable storage medium 1414. The software, when executed by the processor 1412, causes the processing circuit 1402 to perform the various functions described supra for any particular apparatus. The processor-readable storage medium 1414 may be used for storing data that is manipulated by the processor 1412 when executing software.

In one configuration, the apparatus 1400 includes modules or circuits 1404, 1410, 1426 for reporting a configuration including communications capabilities of the apparatus 1400 to a SLIMbus manager, modules or circuits 1410 for receiving one or more configuration messages from a primary data line of a SLIMbus 1424, modules or circuits 1408 for reconfiguring a communications interface 1426, and modules or circuits 1410, 1426 for communicating with a first device over a first data line of the SLIMbus 1424 while communicating with a second device over a second data line of the SLIMbus 1424.

The aforementioned means, modules and circuits may be implemented, for example, using some combination of a processor 206 or 236, physical layer drivers 210 or 240 and storage media 208 and 238 illustrated in FIG. 2 and deployed in a network configuration illustrated by FIG. 9.

It is understood that the specific order or hierarchy of steps in the processes disclosed is an illustration of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." Unless specifically stated otherwise, the term "some" refers to one or more. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed as a means plus function unless the element is expressly recited using the phrase "means for."

What is claimed is:

1. A communications method, comprising:

determining communications capabilities of a first device coupled to a serial low-power inter-chip media bus (SLIMbus), wherein the communications capabilities identify a number of data wires coupled to the device including a secondary data line that couples the first device to a second device; and

sending a configuration message from a third device to the first device over a primary data line of the SLIMbus; and

providing a clock signal that controls timing of transmission on at least the primary data line,

wherein the configuration message causes the first device to be configured for communication with the second device over the secondary data line, and

wherein the configuration message includes control information reserving the secondary data line for communications between the first device and the second device.

2. The method of claim 1, wherein the first device is configured to communicate with the second device over the secondary data line using a SLIMbus protocol.

3. The method of claim 1, wherein the first device is configured to communicate with the second device over the secondary data line using a non-SLIMbus protocol.

4. The method of claim 1, wherein communications on the secondary data line is synchronized using the clock signal.

5. The method of claim 1, further comprising:

allocating a plurality of communications channels in time slots on both the primary data line and the secondary data line, wherein the first device communicates with the second device over the secondary data line using one of the plurality of communications channels.

6. The method of claim 1, wherein the secondary data line connects the first device with the second device independently of the SLIMbus.

7. The method of claim 1, wherein the secondary data line is one of a plurality of secondary data lines of the SLIMbus.

8. The method of claim 7, wherein the control information is generated by a SLIMbus manager provided on the third device, wherein the third device is restricted to communicating over the primary data line.

9. The method of claim 1, further comprising:

sending configuration messages over the primary data line to a plurality of devices; and



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transmitting a reconfiguration command to the plurality of devices,  
 wherein the reconfiguration command causes each of the plurality of devices to adopt a configuration in accordance with at least one configuration message.

10. The method of claim 9, wherein the first device is configured to relay one or more configuration messages sent over the primary data line to a fourth device.

11. An apparatus, comprising:

a communication interface configured to couple the apparatus to a first device and to a second device through a serial low-power inter-chip media bus (SLIMbus);

a SLIMbus manager; and

a processing circuit configured to:

determine communications capabilities of the first device the SLIMbus, wherein the communications capabilities identify a number of data wires coupled to the first device; and

send a configuration message to the first device over a primary data line of the SLIMbus; and

provide a clock signal that controls timing of transmission on at least the primary data line,

wherein the configuration message causes the first device to be configured for communication with the second device over a secondary data line, and

wherein the configuration message includes control information reserving the secondary data line for communications between the first device and the second device.

12. The apparatus of claim 11, wherein the first device is configured to communicate with the second device using a SLIMbus protocol.

13. The apparatus of claim 11, wherein the first device is configured to communicate with the second device using a non-SLIMbus protocol.

14. The apparatus of claim 11, wherein communications on the secondary data line is synchronized using the clock signal.

15. The apparatus of claim 11, wherein the processing circuit is configured to:

allocate a plurality of communications channels in time slots on both the primary data line and the secondary data line, wherein the first device communicates with the second device using one of the plurality of communications channels.

16. The apparatus of claim 11, wherein the secondary data line connects the first device with the second device independently of the SLIMbus.

17. The apparatus of claim 11, wherein the secondary data line is one of a plurality of secondary data lines of the SLIMbus.

18. The apparatus of claim 17, wherein the control information is generated by the SLIMbus manager, wherein the apparatus is restricted to communicating over the primary data line.

19. The apparatus of claim 11, wherein the processing circuit is configured to:

send configuration messages over the primary data line to a plurality of devices; and

transmit a reconfiguration command to the plurality of devices,

wherein the reconfiguration command causes each of the plurality of devices to adopt a configuration in accordance with at least one configuration message.

20. The apparatus of claim 19, wherein the first device is configured to relay at least one configuration message sent over the primary data line to a third device.

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21. A communications method, comprising:

receiving one or more configuration messages from a serial low-power inter-chip media bus (SLIMbus) primary data line;

reconfiguring a communications interface in response to a reconfiguration command and based on the one or more configuration messages; and

communicating with a first device over a first data line while communicating with a second device over a second data line after reconfiguring the communications interface,

communicating with a first device over a first data line while communicating with a second device over a second data line after reconfiguring the communications interface,

wherein the second data line is reserved for communications with the second device,

wherein the reconfiguration command is received from the first device, and

wherein the first device is restricted from communicating over the second data line.

22. The method of claim 21, wherein the first data line comprises the SLIMbus primary data line or a SLIMbus secondary data line.

23. The method of claim 21, wherein the second data line comprises a SLIMbus secondary data line that employs a framing and control configuration used by the SLIMbus primary data line, and wherein the framing and control configuration defines a root clock frequency and gearing and is used to calculate a frame boundary.

24. The method of claim 21, wherein communications on the second data line is controlled by a non-SLIMbus protocol.

25. The method of claim 21, further comprising:

reporting communications capabilities information to a manager in the first device, wherein the configuration messages are generated in response to the communications capabilities information.

26. An apparatus, comprising:

a processing circuit configured to:

receive one or more configuration messages from a serial low-power inter-chip media bus (SLIMbus) primary data line;

reconfigure a communications interface in response to a reconfiguration command and based on the one or more configuration messages; and

communicate with a first device over a first data line while communicating with a second device over a second data line after the communications interface is reconfigured,

wherein the second data line is reserved for communications with the second device,

wherein the reconfiguration command is received from the first device, and

wherein the first device is restricted from communicating over the second data line.

27. The apparatus of claim 26, wherein the first data line comprises the SLIMbus primary data line or a SLIMbus secondary data line.

28. The apparatus of claim 26, wherein the second data line comprises a SLIMbus secondary data line that employs a framing and control configuration used by the SLIMbus primary data line, and wherein the framing and control configuration defines a root clock frequency and gearing and is used to calculate a frame boundary.

29. The apparatus of claim 26, wherein communications on the second data line is controlled by a non-SLIMbus protocol.

30. The apparatus of claim 26, wherein the processing circuit is configured to:

report communications capabilities information to a manager in the first device, wherein the configuration messages are generated in response to the communications capabilities information.

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